Geddes Q-18
Natchez Fleet

BANK PROTECTION

MISSISSIPPI RIVER

PLANT, METHODS, AND MATERIAL IN USE ON WORKS UNDER DIRECTION OF MISSISSIPPI RIVER COMMISSION

Barth

Prepared Under the Direction of the Chief of Engineers U. S. Army, March, 1922, in the Office of the Secretary of the Mississippi River Commission

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

BANK PROTECTION
MISSISSIPPI RIVER

PLANT, METHODS, AND MATERIAL IN USE ON WORKS UNDER DIRECTION OF MISSISSIPPI RIVER COMMISSION

Prepared Under the Direction of the Chief of Engineers U. S. Army, March, 1922, in the Office of the Secretary of the Mississippi River Commission

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

CERTIFICATE: By direction of the Secretary of War, the matter contained herein is published as statistical information and is required for the proper transaction of the public business.

BANK PROTECTION.

The plan of improvement of the Mississippi River originally recommended by the commission included revetment, or bank-protection works, for the purpose of preventing caving of the banks at points where such caving, if unchecked, would make it impossible to obtain the desired contraction of the low-water channel, or result in injurious changes of current direction below. The following extracts are from the annual report of the Mississippi River Commission for 1887:

Five years' experience in Lake Providence Reach warrants the statement that it is impossible to narrow the low-water channel in that reach through permeable contracting works alone, by any expenditure of money or continuance of work. The works may be constructed and deposits secured by the thousand acres, but unless held to its place at certain points of impingement, the current will run away from these and leave them utterly useless and ineffectual. * * *

LETTER TRANSMITTING THE COMMISSION'S PROJECTS TO THE SECRETARY OF WAR.

OFFICE OF MISSISSIPPI RIVER COMMISSION,
St. Louis, Mo., November 27, 1886.

SIR: The river and harbor act of August 5, 1886, imposed on the Mississippi River Commission the condition—

"That no works of bank protection or revetment shall be executed in said reaches or elsewhere until after it shall be found that the completion of the permeable contracting works and uniform width of the high-water channel will not secure the desired stability of the river banks."

This limitation is based, it is believed, on the theory that a river, if once regulated, will not scour its natural banks. The commission is somewhat familiar with the opinions and writings of hydraulic engineers, and, so far as it is advised, this theory is totally unrecognized by any authoritative writer on hydraulics. It is universally recognized by such writers that, in general, when a large obstruction is placed on one bank of a river a corresponding wearing away of the opposite bank occurs in consequence. There is no evidence that a regulated river will not cave its banks, and in most cases it is impossible to build permeable contracting works or secure any narrowing of the channel by them without holding the banks in their immediate neighborhood while the work is going on. The unprotected banks would recede while the contracting works were being built. These general views are fully confirmed by the experience of the commission on the Mississippi River.

The contraction works at Gold Dust, Plum Point, Duncansby, and Baleshed have been followed by caving on the opposite bank, whose immediate result is, by again enlarging the cross-section of the river, to destroy any beneficial

results the contraction works might otherwise produce. That such works may secure any valuable permanent contraction, the opposite bank must, in general, be held by protection works.

In the opinion of the commission the idea that the Mississippi River can be permanently improved by contraction works alone is purely visionary and theoretical, contradicted by experience, and not supported by any good authority. To adopt such a system is, in the opinion of the commission, to waste public money. Holding these views, the commission, as engineers, can not recommend to Congress so futile an undertaking. * * *

The convictions expressed by the commission in its letter to the Secretary of War, touching the futility of an attempt to improve the river channel by levees and contraction works alone, are still entertained and have been strengthened by the experience of the present season. It would be impossible for works of improvement to operate more successfully than have those at Plum Point Reach. The regulated channel has maintained its width and depth and the current its location and direction, with no substantial variation. These results have been obtained by permeable contraction works and works of bank protection combined. They could not have been obtained by either alone. The commission believes that it would be impossible for any intelligent man to go to the reach and look at what has been done and the results which have been achieved without seeing clearly that that part of the work which has operated, like the key of an arch, to hold all other parts in place has been the revetment in Fletchers Bend.

At Lake Providence Reach as great depth of channel has been obtained as at Plum Point, but the channel has not retained its location and direction as steadily, and in the present situation there is less promise of permanence of the good results obtained. This is accounted for by the fact that the revetment work in that reach is less complete and has suffered more injury, and that there has been in consequence more caving of bends and more shifting of the channel.

The practical execution of works for bank protection upon such large scale and in situations so difficult as those found on the lower Mississippi was at the beginning a problem transcending the experience of engineers. There was no road to success except by experiment. Since then much valuable experience has been gained, improved methods of construction have been devised, better results have been obtained, and the cost, considering the results, lessened. The form of revetment mostly employed consists of continuous mattress under water, and graded bank, grillage, and stone covering above the low-water line. At New Orleans a revetment has been employed consisting of submerged spurs placed against the caving bank. This form was cheaper than a continuous mattress would have been at that place and appears so far to be successful. At the lower portion of the Memphis city front a revetment has been constructed consisting of detached spurs extending to high-water mark. This was more expensive than a continuous mattress would have been at the same place, but in the situation there presented, the bank to be protected being at the foot of a high, crumbling bluff, the spurs seemed to be the better form. This work was done under the direction of Capt. S. S. Leach, the district officer in charge, but mainly at the expense of private citizens. It has passed through one flood without injury and gives every promise of permanent success.

These three forms of revetment—the continuous mattress, the submerged spur, and the spur extending to high-water line—are all that have been tried. A fourth form is possible, consisting of discontinuous mattresses placed at intervals against the bank. It is possible that in some situations this would

be found practicable and economical; but it is to be remembered that in such constructions as these experiments in search of cheapness are themselves very expensive.

Under date of July 7, 1881, the committee on construction was authorized to commence the revetment of the bank below low water with brush and wire mattresses of 2 inches in thickness of solid brush at the following localities in the Plum Point reach, viz:

Commencing 2,000 feet above Forked Deer Island Chute and extending 6,000 feet below the chute, left bank.

20,000 feet in Canadian Reach, right bank.

24,000 feet from Ashport to Johnsons, left bank.

22,000 feet from Fletchers to Elmots, right bank.

16,000 feet from Tanzas to Craighead Point, right bank.

In one badly caving bank the experiment shall be tried of making the mattress 6 inches thick for 3,000 feet, and in another for a like distance the thickness shall be made 12 inches. These thicknesses shall, if possible, be of single mattress; if not possible, they shall be composed of the smallest practicable number of thin ones laid one immediately after the other. Work of a similar description in construction was authorized at Lake Providence.

Under date of October 17, 1881, the following resolution was passed by the commission:

That it is the desire of the commission that such experiments, both on construction and quality of revetments, shall be tried by the committee on construction as shall lead to conclusions as to the strength and density required under the different conditions presented by the river bank. That these experiments shall include different thicknesses (ranging from 2 to 12 inches) and different degrees of compactness, elasticity, and roughness of surface.

The method of operation comprised three parts: First, the revetment of that portion of the bank below the water surface; second, the grading of the bank above the water surface to a slope suitable for receiving the upper bank protection; third, placing the upper bank protection.

EARLY METHODS OF MATTRESS CONSTRUCTION.

The first bank-protection work done under the direction of the Mississippi River Commission was begun late in the season of 1881. A method used on the Missouri River for checking bank erosion was tried at the head of Bullerton Bar (166). This protection work consisted of wire screens having meshes 3 feet square, hung from piles with the bottom edge of the screens at the low-water plane. A small mat, 500 feet long, was built in connection with this work. The experiment was a failure, as the piles were washed out and the mat was destroyed by the high water of 1882.

During the season of 1882, ways 200 feet long and 75 feet wide, with stringers spaced 5 feet apart and sloping 4 inches to the foot, were built on the shore for use in the construction of mattresses at

Memphis, Tenn. Lines of cottonwood poles 4 to 5 inches in diameter were placed at right angles to the skids on the ways at intervals of 4 feet, and similar poles were placed at right angles to and across these, also spaced 4 feet apart. The lines of poles were joined at their intersections by carriage bolts 9 inches long. On this grillage were placed three layers of green willow brush. The first layer of brush was perpendicular to the top lines of poles in the grillage, and each succeeding layer was perpendicular to the layer next below. On top of the brush was placed a pole frame work similar to the bottom grillage. The two grillages were united at intervals of 8 feet with oak rods 1 inch in diameter and 4 feet long passing through both frames. The frames were joined together with wire ties in addition to the rod connections.

These mats were each 120 by 60 by 2 feet. This construction was similar to that used by Maj. W. H. H. Benyaurd, Corps of Engineers, United States Army, on bank protection in Memphis Harbor during the period 1877 to 1880. During the year 1881 Major Benyaurd had substituted a grillage of wire for the pole grillage.

A frame of poles was first placed along the four edges of the mat, and the wires were stretched across them at intervals of 6 feet in both directions, the wires being well secured to the poles, and where the wires intersected each other tie wires were twisted around them and were then led up temporary stakes, which were driven in the ground to secure them in place, these stakes extending about 2 feet above the ways. Four alternating layers of brush were then placed to make a total thickness of 18 inches, and on this was placed a network of wires similar to the bottom, to which they were tied with the short wires carried by the stakes. The top and bottom poles forming the selvage edges were also well wired together at close intervals, being first compressed together for this purpose.

The experience gained from the use of small detached mats showed that they were expensive to construct and difficult to place so as to cover the entire bank, and that they were not long enough to reach to the necessary depth of water. During the season of 1882 and 1883 the continuous woven mattress was used.

The continuous mattress was made floating on the surface of the water, directly over where it was to lie when sunk. A barge for its construction was prepared and fastened by cables to the bank at the point which was to be the upstream end of the mattress. At Bullerton the type used consisted of a wire net base of No. 8 galvanized wire with meshes 3 feet square. The brush was laid normal to the river on top of this net in a single layer 12 to 15 feet wide. This layer of brush was tied down by poles perpendicular to the brush and spaced 5 feet apart. Each pole had its butt end thrust over the brush and under the transverse wire of the net. The tops of the poles were then pulled down over the brush and wired to the net, thus holding down the brush. The usual care of so distributing the brush that too

many butts would not lie on the same line was taken. These mats were built on mat barges specially designed for this work, the nets being woven on the barges as fast as construction of the mat progressed and the brush being delivered upon the net by overhead carriers.

This type formed a very flexible mat, but one of little strength, as it was almost impossible to so weave the net that the wires would have equal stresses. As each pole, when tied down, formed a sort of flat arch, much of the brush toward the middle of the layer was imperfectly held down and was liable to displacement in sinking, thereby not only causing much of the stone ballast to drop through, but also leaving openings through which the current could scour the bottom. Mats of the same type were used as foot mats for dikes and as subaqueous mats in bank revetment. For the former the width varied from 40 to 100 feet, while the width of mattresses for revetment was made from 100 to 175 feet, the largest proportion being of the first-mentioned width.

The type used at Ashport (155 L), Fletchers Bend (161 R), Hopefield Bend (223 R), at the head of Mayersville Island (533 L), and at Delta Point, La. (600 R), consisted of poles and brush, with the brush woven alternately over and under the poles like basketwork. The usual method of construction of the woven brush and pole mattress was described by Assistant Engineer H. St. L. Coppee, November 30, 1882, as follows:

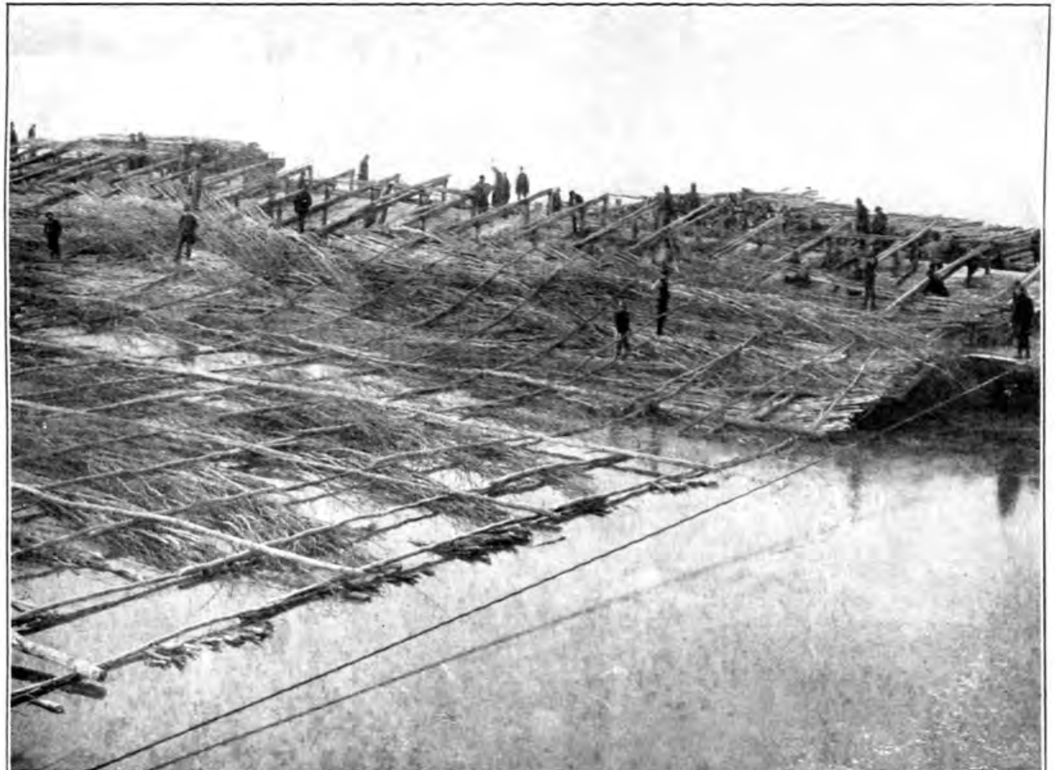
The mattresses are constructed after the plan adopted by Major Ernst at his works near St. Louis.

They are built on ways which were originally erected for continuous wire-mattress construction. These ways are composed of two barges, each 150 by 20 by 3 feet deep; the gunwales of cypress, the bottom ones 8 inches and top ones 6 inches thick; the bottoms of the barges are of yellow pine 2½ inches thick. The barges are placed parallel to each other, 9 feet apart, and rigidly connected by a beam 8 by 18 inches by 30 feet long bolted across each end. The space between the barges is spanned at intervals of 5½ feet by 4 by 6 inch sills, which support the posts on which the runs rest. There are also horizontal diagonal braces to give stiffness to the structure. The runs are transverse to the length of the barges and 5 feet 6 inches between centers. They are of 4 by 9 inch cypress, supported by 4 by 6 inch posts, 6½ feet apart, which rest on 4 by 6 inch sills laid across the bottoms of the barges. The runs at the upper end are 13 feet 3 inches above the bottoms of the barges, and at the lower end (8 feet outside of outer barge) within a few inches of the water surface. A floor is placed 4 feet below the top of runs and parallel thereto. A platform 8 feet wide projects from the upper side of the ways on a level with the upper edge of the floor and extends the whole length of the structure. The mode of making the mattress on these ways is as follows:

A low gunwale flatboat, 170 feet long by 26 feet beam, is placed with bow to the shore and stern into the stream, and held in that position by 1½-inch lines leading to deadmen on the bank, and anchors in the stream above. On the lower (downstream) side of this boat and firmly held to it by 1-inch lines are

the ways, placed with the lower end of the runs upstream, and the bows of the barges against the bank. The position of these two boats is now directly over that portion of the lower slope of the bank which is to be revetted. The construction of the mattress is commenced by laying 30-foot willow poles, 5 inches at large end, across the runs and near their lower ends. These poles are lapped from 4 to 6 feet and fastened together with No. 12 wire and four or more 6-inch boat spikes. The number of these poles depends upon the width of the mattress desired. Longitudinally between the runs, about 6 feet apart, are placed willow poles of the same dimensions, or perhaps a little smaller, with their large ends resting on the transverse system, and tightly wired and spiked to them. Another set of transverse poles fastened in the same manner as the first are then placed on the butts of the last-mentioned poles, and all three sets wired and spiked together with No. 12 wire and 10-inch spikes. Before commencing to weave the mattress this upper end or frame is fastened by 1-inch lines to the low-gunwaled flat to which ways are held. Brush is then woven over and under the longitudinal poles, the brush being about 30 feet long by 3 inches at the butt. The weaving is accomplished by placing the brush over the outside pole, under the next, over the next, and so until its end is reached, when it is forced down the runs and poles until the transverse poles are reached, to which, by means of mauls, it is caused to fit tightly; this operation is carried on all along the ways by different gangs of men and repeated until the 30 feet of poles is nearly filled with woven brush, only space enough being left to spike and wire on new poles on which to continue the weaving. In conjunction with this work 30 and 40 penny nails are driven through the butts of the brush on the inside and outside edge of the mattress, fastening them to the inside and outside longitudinal poles, respectively. At every 100 feet in length of the mattress transverse poles similar to those at the upper end are used in order to give it more strength; also longitudinal poles are placed and bound on it 12 feet apart for the purpose of forming a crib to keep the rock from rolling off when sunk in deep water; the number and size of these depend entirely on the slope of the bank. When a mattress is constructed to the upper end of the runs and therefore covers the entire ways, it becomes necessary to take it off in order to continue the operation and make it the desired length. (We are making them about 300 feet long.) To do this the lines holding the ways to the flatboat are slackened and the ways caused to drift down by the impact of the current, and in so doing slide from under the mattress. Should the current not have sufficient force, they are pulled down by means of capstans (fastened below the working platform) holding lines to anchors and the shore below. The ways are only moved the length of a pole for each shift until the end of the mattress is reached, when they are taken away and the mattress allowed to float, held at the end by the flatboat, and at its shore side by 1-inch lines leading to deadmen 30 feet apart. In order to sink the mattress, boats containing rock are brought to its outer edge and fastened there with lines at intervals of 10 feet; it is then loaded uniformly with the rock until there is a heavy strain on these lines. At a word the lines are cut, and as it sinks the barges are pulled over the surface it occupied and rock thrown out in quantities sufficient to insure its remaining on the bottom. The number, size, and position of the lines depend on the force and direction of the current or currents and the depth of the water. After the mattress is sunk, sharpened piles are driven through its shore side to guard against its sliding should the slope be steep. The mattresses now being constructed are 150 by 280 feet.

We make from 60 to 70 feet per day with 52 men—30 men to do the weaving, 6 at the mauls, 6 handling the willows from barge to ways, 6 binding poles, and 4 linesmen. The mats are always made to lap, the upper edge of the lower mat lapping over the lower edge of the upper one at least 15 feet.



NO. 1.—WEAVING SUBAQUEOUS MAT.

NO. 2.—WEAVING SUBAQUEOUS MAT. PORTION IN FOREGROUND BALLASTED READY FOR SINKING.

NO. 3.—BALLASTING SUBAQUEOUS MAT.

NO. 4.—GENERAL VIEW OF SUBAQUEOUS MAT.

NO. 5.—SINKING SUBAQUEOUS MAT—BEGINNING OF OPERATIONS.

NO. 6.—SINKING SUBAQUEOUS MAT—SECOND STAGE.

NO. 7.—SINKING SUBAQUEOUS MAT—CLOSE OF THE OPERATION.

The method of construction used at Mayersville Island was described by Assistant Engineer Arthur Hider, November 15, 1883, as follows:

Willows from 2 to 3 inches in diameter at their larger ends and from 30 to 50 feet in length were woven on large cottonwood poles from 3 to 4½ inches diameter at small end, placed about 8 feet apart on ways or skids erected on a boat for that purpose. They were pushed down the skids close together over and under alternate poles, forming woven work; then brought into close contact by driving the brush together with heavy wooden mauls. Alongside of every weaving pole or alternate poles, determined by the width of the mat and the longitudinal strength required, iron rods with welded eyes at each end were placed as the mat was built; the ends of these rods were connected with lap-rings or clevises. These rods were to give the necessary longitudinal strength to the mat, and prevent it breaking asunder while being sunk, and allow it to adjust itself to any irregularities on the bottom. The mat was then further strengthened by binders made of poles placed on top, securely fastened to the mat with wire to the weaving poles.

In wide mats, and where the current was swift and the water deep, additional longitudinal strength was obtained by the use of No. 8 wire twisted in the form of a cable extending on top of the mattress, securely fastened at intervals by wire to the weaving poles. The upper end of the mat while being constructed was held in place by lines passed under a mooring barge leading to fastenings on the shore above. The mooring barge was placed with one end next the bank, the outer end being kept in place by lines leading to suitable fastenings on shore. The head of the mat was held up by small lines passing over the side of the mooring barge, to which they were fastened, which were slacked as the head was sunk; additional lines leading from the mat to the bank were placed along the mat at intervals, so connected with it by iron clevises as easily to be freed after the mattress had been sunk in position.

The use of the mooring barge was to prevent drift from lodging on the head of the mat, and to keep it from being submerged until it was ready to be sunk. The mats were sunk by first loading the edge next shore along the slope with rock, and afterwards by throwing rock on it, beginning at a suitable distance below the head to allow the mat to reach the bottom without breaking. The head was then sunk last.

The methods of constructing and sinking mattresses are shown on Plates Nos. 1 to 7.

During the season of 1883 some changes were made in the woven-type brush and pole mattress in the first district for the purpose of giving it greater strength. Five No. 8 galvanized wires were run the full length of the mat directly over the five outside weaving poles and one bottom wire of the same kind under the outside weaver, and a set of longitudinal top poles, spliced together butts and tops, was placed over each set of weaving poles. This set of poles was placed after the mat was afloat and was wired to the weaving poles every 6 feet.

In revetment work at Hopefield Bend during the season of 1884 the mats were made 150 feet wide, the shore edge being held against a line of piles driven at about the 5-foot contour line below low water, or an average of about

25 feet farther outstream than the mats of the previous year. This, with the 10 feet additional width, increased the total width of the subaqueous work about 35 feet. Instead of weaving one brush at a time over and under the poles for its entire length, a number of pieces were handled at once; these were spread out in a horizontal layer, with their butts over one pole, which they lapped about 2 feet. The brush was then passed under the next pole and over the second, and the tops were then thrown over on the mat already constructed. The tops of the brush thus woven were inclined upstream at a considerable angle. Other bunches of brush were placed in the same manner with their butts shifted two poles apart, until the strip was woven entirely across the mat. Then the direction of the brush was reversed and another strip woven, the butts this time being placed over the poles intermediate to those on which the butts of the first strip were placed and the tops thrown over on the first weaving, which they crossed at an angle, thus making practically a double thickness of brush. This was called the diagonal method of weaving, and, while making a considerably thicker mat, it still contained many and fairly large holes. The top binding poles were then placed as heretofore and transverse poles wired on at 8-foot intervals. To increase the strength of mat, five iron rods, one-half inch in diameter, and two wire ropes of five-eighths inch diameter were placed longitudinally along the binding poles while other iron rods or wire strands were placed across the mat and along the transverse poles at intervals of about 40 feet, the ends of these wire strands being secured to fastenings on the shore or to the piling. All rods and wire strands were secured to the mat at intervals of about 16 feet with tie wires. The first iron rods used were 16 feet long with a welded eye in each end, and these were joined together with a malleable iron shackle and pin. Later, the eye was formed by turning the rod back and twisting it two or three times around itself. This was more expedient and insured more certainty in strength, as the welded eyes were often unreliable. The wire strands used were made on the bank by twisting from four to eight wires together, according to the strength required, and were made in lengths to suit their use. These were generally used for the transverse and shore anchor ties and were also placed along alternate weaving poles. (Occasional Papers No. 41, pp. 144–145.)

During the season of 1884 the mat work at Memphis Harbor was made stronger by using more and larger iron rods and wire strands and by joining the former together in a more efficient manner. Thus, instead of using single rods with welded eyes and uniting them with malleable iron shackles, the rods were made with twisted eyes, as already described. The size of the rods was also increased to three-fourths inch diameter. These were placed along alternate poles or 16 feet apart, and along the weaving poles under these rods were placed handmade wire strands. These changes in construction added greatly to the tensile strength of the mats.

During the season of 1886 in Hopefield Bend (223 R) some changes were made in cabling the mats, the use of iron rods was discontinued and wire strands in continuous length were used instead. Short wire strands were run along alternate weaving poles as before, and from all the strap lines continuous-length wire strands were run over the entire length of the mat and tied to it every 16 feet. The transverse cables were placed every 32 feet and made continuous from the outer edge of the mat up the bank work to fastenings on top.

Failure of revetment.—An examination made at low water of breaks which have occurred suggested that the revetments have been destroyed by one of the following causes:

(1) Insufficient width which allowed undermining by scour at the channel edge of the subaqueous mats.

(2) Want of flexibility in the subaqueous mats, which prevented them from following the scour without rupturing.

(3) Want of compactness or too great permeability of the mats, by reason of which the material under the mat is scoured out either by direct attack by the current through them or by the return flow from the saturated strata on a receding river. To obviate these objections as far as practicable the plan adopted for the last season's work was to make the mats as wide as the mat barges would allow (240 feet), to use smaller brush and weave it more closely than heretofore, to make the connecting mats much thicker and with greater lap over the river mats, and to protect the bank above low water by a layer 10 inches thick of riprap stone. (Report of Capt. S. W. Roessler, Corps of Engineers, United States Army, printed in annual report of the Mississippi River Commission for 1893, p. 3720.)

PRESENT TYPES OF BANK REVETMENT.

Framed mattress.—The frame type of mattress was adopted in the fourth district in 1889, and since that time has been practically the only form of mattress used in that district.

The principal advantage of the frame mattress over other types of mattress construction lies in the fact that it does not necessarily have to be built on the site of the work where it is to be used, but can be constructed at any point on the river above the locality to be protected and towed downstream to the place where it is to be sunk. Mats of this form are especially adapted to use in the fourth district, as they can be safely towed long distances in the comparatively slack low-water current found in this part of the river. The mat itself is a brush raft made up in sections 100 by 150 feet. In sinking, these sections are wired together and joined by poles to form a mat 150 feet in length and as wide as required. The normal width is 300 feet, but widths as great as 600 feet are sometimes required.

The mats are constructed on ways built on the bars where willows are plentiful. Frames are built at the head of the ways, slid down them, and spaced at 10-foot intervals across the full width of the ways.

The following description of the construction of framed mattresses is from a report by Mr. W. G. Price, assistant engineer, printed in the annual report of the Mississippi River Commission for 1888, page 2309:

The frames were composed of two lines of 2-inch by 4-inch timbers 75 feet long, separated 2 inches, and spliced to break joints with pieces 2 feet long placed between them and the whole nailed together. Posts 2 inches by 4 inches and 3½ feet long and 6 feet apart were fastened at one end between these

timbers, each post being secured with one yellow-pine pin three-fourths of an inch in diameter and one 6-inch steel-wire nail. A piece of gas pipe sharpened at one end and the other screwed into a plate of iron was used for making the pins. The end posts were only 2½ feet long, and those next to the end were 3 feet long, so as to make the mattress thinner where they lap together. When the frame had been filled with willows, cap pieces precisely like the bottom pieces first described were put on over the posts, pressed down, and fastened to the post as before. A lever attached to a pair of hooks, similar to ice hooks, was used for compressing the mattress. The frames were placed 8 feet apart and they were filled with two layers of willow poles and three layers of willow brush. The poles were at top and bottom and the brush between, each layer crossing the preceding layer. The bottom layer of poles was nailed to the frames to give sufficient longitudinal strength. As fast as the frames were filled with willows the mattress was hauled off the ways downstream by a rope which led to a capstan on shore, and the top layer of poles and the yellow-pine caps were then put on. The lower end of the float would sink under water from the weight of the mattress, but with a part of the men wearing rubber knee boots they could all keep their feet dry. As much as 123 linear feet of mattress was woven in one day with a force of 66 men. I think with a force of 80 men 150 linear feet can be finished per day. In order to accomplish this, it would be necessary to have always four barges of willows on hand to unload from. The bank-protection mattresses were the same as those described, except the frames were 12 feet apart.

Ten mattresses, each 100 by 150 feet, is considered a safe tow, although more than this number can be towed. The frame mattresses are sunk in place by being weighted with stone in practically the same manner as that employed in sinking woven and fascine mattresses. About 15 pounds of stone per square foot of mat are required.

In a report on bank protection, dated June 6, 1896, made by Assistant Engineer H. S. Douglas, the following occurs:

Going somewhat into details it may be stated that one of the principal objections to both the fascine and woven mattress is that they must be built on the spot where they are to be sunk and of the full dimensions required. * * * With the framed mattress it can be built at any point above the proposed locality where it is to be sunk that willow or other suitable brush can be obtained. The brush will require to be handled but once, directly from the bank into the mattress. The length of but one barge extending out into the river is required, and that can be placed in a sheltered locality where the possibility of accident is reduced to a minimum. I can conceive of a locality near the foot of a sand bar overgrown with willows, where ways on the bank would answer, and no floating plant of any kind be required. Construction can be commenced, if desired, during high water, and all of the mattresses built so that advantage can be taken of a favorable stage of the river to sink. The longer time after the mats are built before they are sunk the less rock it will take to sink them. By using a pump, with hose and nozzle, to wash out collected sediment the mattress can be parked and kept afloat for an indefinite length of time.

Fascine mattress.—During the period January 11 to 28, 1893, the first experiment was made with a fascine mat. The work was in

connection with repairs to the Daniels Point revetment. The fascines were made of small brush, and were from 50 to 100 feet long and 12 inches diameter. They were tightly compressed and wired together every 3 feet. These fascines were to form the warp of the mattress, pairs of longitudinal strand cables spaced 8 feet apart forming the woof. Long cable clamps to clamp together the top and bottom cables were used every 3 feet, the fascines being first compressed together; a top grillage of poles was then placed over the whole.

By resolution of the commission, dated May 9, 1893, the district officers of the first, second, and third districts were directed to submit, by June 15, 1893, "designs for underwater mattress work which shall fulfill the conditions that the outer 100 feet of the mattress shall be flexible enough to follow scouring at its edge; that the mattress shall be thick enough and compact enough to prevent the possibility of scour through it; that the mattress, when once down, shall be permanent; and that the use of some nondestructible material for fastening together may be considered."

The fascine mattress was adopted as the standard form for the subaqueous mattress in the first, second, and third districts in 1893. The following description of the plant used and the method of construction is printed in the annual report of the Mississippi River Commission for 1894, pages 2867 to 2871:

Two forms of fascine mattress have been used:

1. Mattresses in which the fascines are placed normal to the current.
2. Mattresses in which the fascines are placed parallel with the current.

The first-mentioned type was used at New Madrid, Hopefield Bend, Ashport Bend, Fletchers Bend, and for the first three mats at Bullerton Towhead. Only one mat, the last at Bullerton, was constructed with the fascines placed longitudinally.

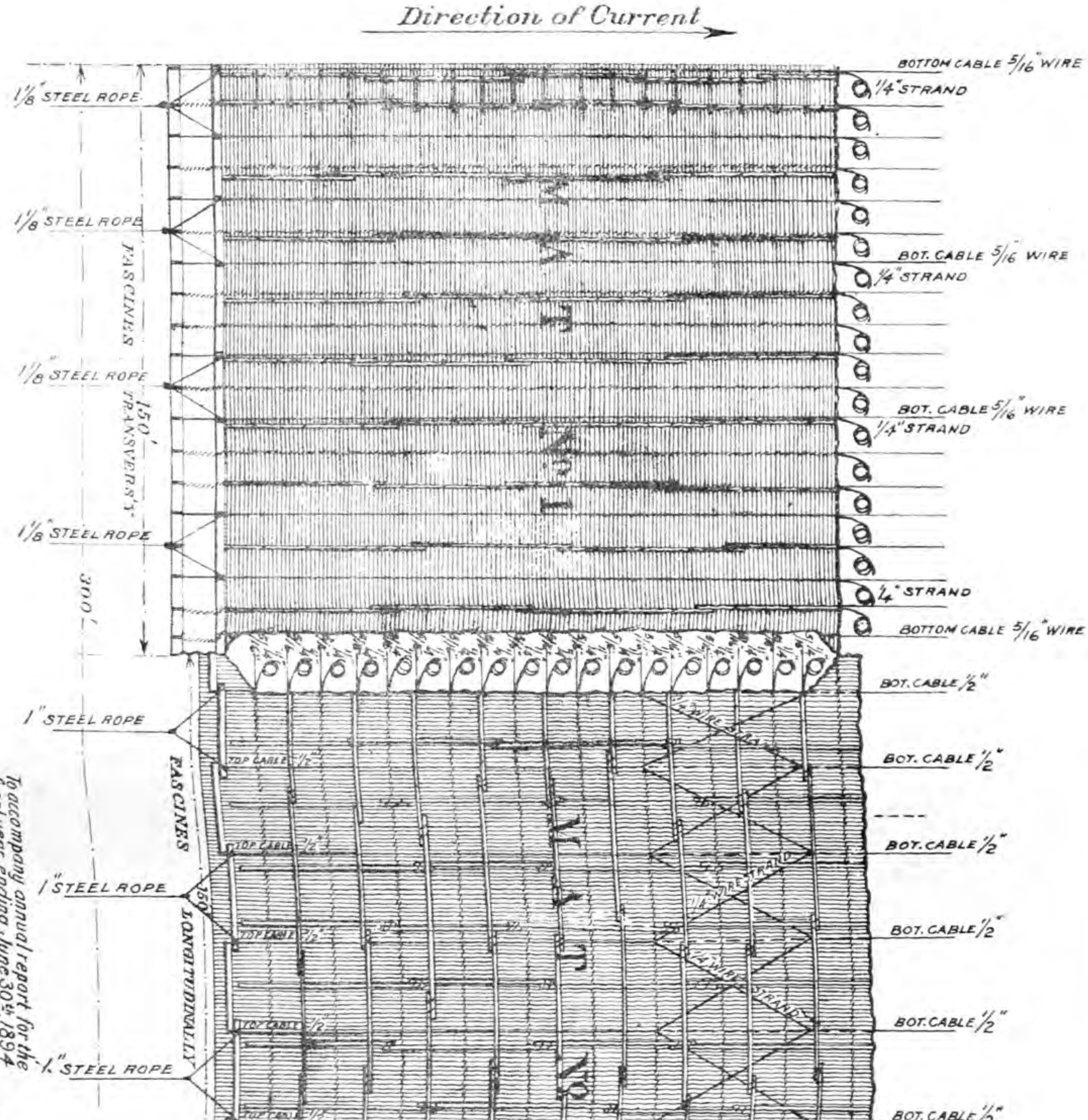
Mattresses with the fascines normal to the current.—The plant required consists of one set of mooring barges, one set of barges with inclined ways, and one set of fascine barges. The barges of each set when placed end to end had a length equal to or greater than the width of mattresses to be constructed. The mooring barges were of the same construction heretofore used with the woven type of mattresses, and were moored across the current in the same way. The mattress barges were also the same as heretofore used, with the following additions: Underneath the platform were placed a number of cable drums, one under each inclined way or skid, on which were wound and from which were paid out, as the construction of the mattress progressed, the steel-wire strand which constituted the longitudinal strength of the mattress and to which the fascines were attached or woven by the method to be hereafter described. The distance between the drums was 8 or 9 feet, according to the particular barges used. At the highest point of each way an iron sheave was placed, over which was passed the strand from the corresponding drum. The drums were all provided with friction breaks, by which a uniform tension was kept on the strands while the mat was in process of construction. The fascine barges were ordinary square-end decked barges, on which were erected tem-

porary platforms the same level as the platform of the mattress ways. These barges were put end to end and lashed parallel to and close up to the downstream side of the mat ways. On the side of the platform nearest the mat ways were erected the formers in which the brush was laid, compressed, and bound into fascines.

Construction of mattress.—The mooring barges being properly moored in position across the current, the mattress ways, to which had been lashed the fascine barges, were brought in position on the downstream side and secured to the mooring barges by three lines, one at the center and one at each end. The first step was to construct the "mat head." This consists of a bundle of poles, 2½ to 3 feet in diameter, well bound together by wire strand so as to form a beam of great strength, of some rigidity, but having also considerable flexibility. The poles were of hardwood, 5 to 8 inches in diameter at the butt, and laid so as to break joints with each other. The beam is as long as the mat is wide, and forms the connecting link between the mooring cables and the mattress. It was moored to the bank by steel-wire cables, independent of the moorings of the mooring barges. The number of cables used depended on the width of mat and strength of current. Eight cables have been used for a mat 300 feet wide. They are spaced at unequal distances apart, being closest together near the outstream end, where the current is strongest, and farthest apart toward the shore, where the current is more moderate. At each point where a cable is to be attached a heavy manila rope, doubled, is wound around the mat head as indicated on Plate 8. Its free ends are passed over the mat and attached to a second and smaller mat head constructed in the mattress 10 feet from the head of the mattress. The other end of the rope is connected by an ordinary shackle to one end of its mooring cable, the other end of the cable being then passed underneath the mooring barge to its anchorage on the bank. The wire strands from the drums on the mattress ways are passed over their proper sheaves and wound around and secured to the mat head. The weaving strands, which are of one-fourth-inch steel strand and for convenience cut into lengths of about 50 feet are also attached to the mat head, one for each of the longitudinal strands upon which the fascines are woven.

For the construction of the fascines and mattress the labor is divided into three gangs, one to hand the brush down from the barges, the second to carry the brush to the formers and to construct the fascines, the third to weave the fascines into the mat. The second party, receiving the brush from the first party, carries it to and distributes it in the formers. The brush is put in two layers, one with the tops in one direction, the other with the tops in the opposite direction, care being taken to break joints as far as possible, and especially to prevent two butts from overlapping. Enough brush is put in to make a fascine 10 to 16 inches in diameter. It is then choked every 8 feet and bound into a fascine by No. 12 steel wire. The chokers consist of iron chains of suitable length and strength, having one end secured to one side of the former. Each chain is brought over the brush and a lever inserted through a ring in the free end and borne down upon by the weight of one or two men, compressing the fascine while it is being bound with wire. The third party, assisted by the second party, raises the fascine out of the formers, slides it along the skids which connect the former with the top of the mattress ways, and down the latter to its position in the mattress next to the mat head. The weaving strand is then passed over the fascine, down underneath it and up between the fascine and mat head, crossing at the same time the bottom longitudinal strand. It is then put into a "Haven clamp" and drawn as taut as four to six men can do it with double block and tackle. The strand is temporarily

GENERAL PLAN



Drawn by R. C. Hoyer

To accompany annual report for the fiscal year ending June 30th, 1894

S. W. Roessler
Captain of Eng'rs.

IMPROVING
MISSISSIPPI RIVER.

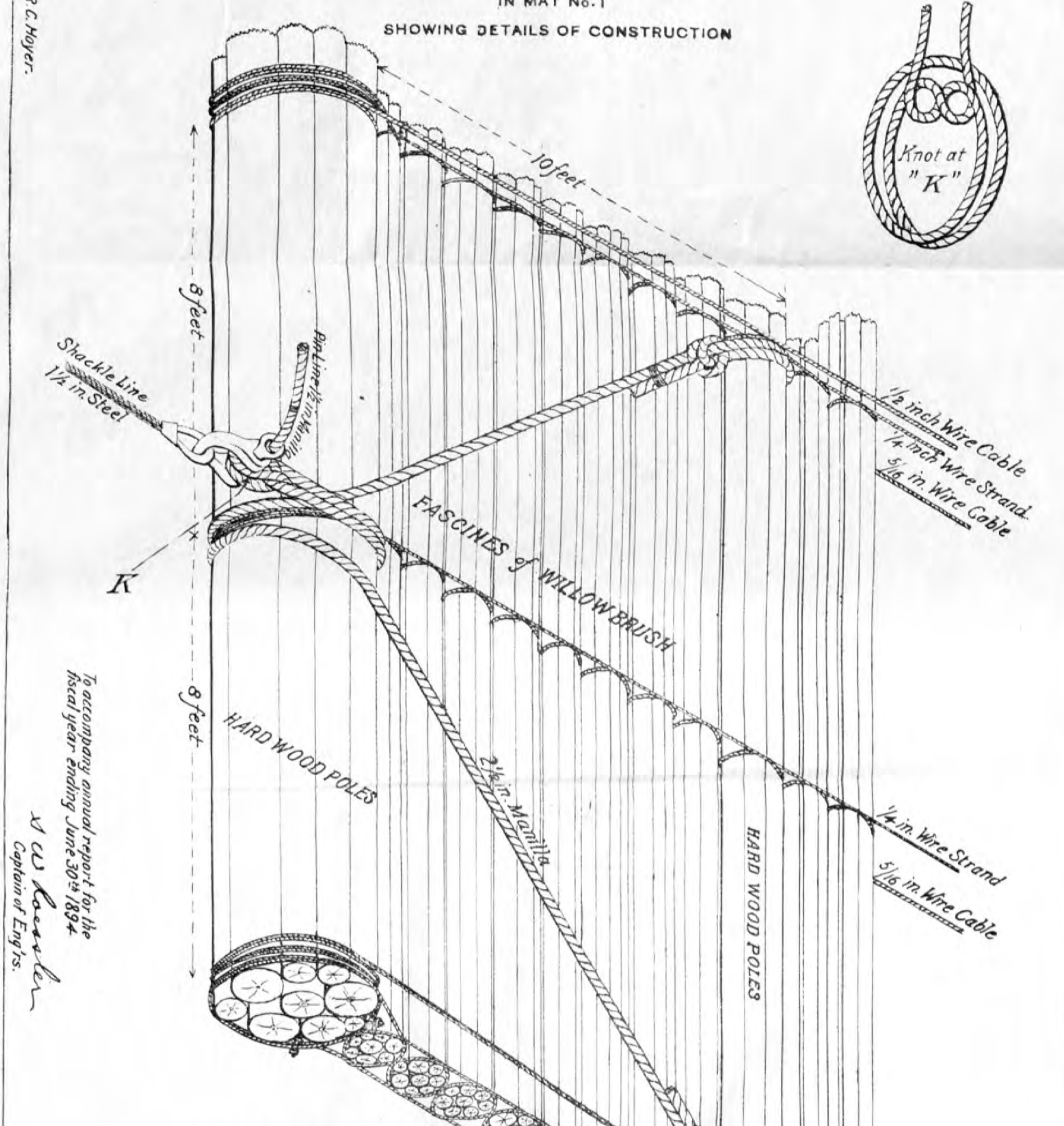
FASCINE MATTRESS

TWO DESIGNS

Traced by H. d'Ailly.

PLATE 9

VIEW OF PART OF THE HEAD
IN MAT No. 1
SHOWING DETAILS OF CONSTRUCTION



IMPROVING
MISSISSIPPI RIVER.

FASCINE MATTRESS

102067—22. (Face p. 13.)

stapled to a pole of the mat head. The second fascine being in place, the weaving strand is passed over the first and second fascine down underneath the second and up between the first and second, at the same time crossing the bottom longitudinal strand as before. It is again attached to the clamp and drawn taut as before by block and tackle and temporarily stapled to a piece of brush in the first fascine. When the strain is first put on the strand, a tap on the pole of the mat head, to which it has been temporarily stapled, is sufficient to dislodge the staple and allow the strand to completely encircle the first fascine. Details of the method of weaving is shown on Plate 9. When the ways have been filled the mattress is launched in the usual way and the construction continued. The tenth fascine is made of hardwood brush or poles, and to it are attached the free ends of the large manila ropes which are wound around the mat head. The weaving and bottom strands are clamped together by a cable clamp every 10 feet, and at points intermediate between the clamps both strands are stapled to the brush to prevent the fascines from separating in the process of weaving. On top of the mattress thus constructed are placed rows of poles, 16 feet apart, extending up and down stream. They are lashed to the fascines by No. 7 silicon bronze wire every 5 feet and at intermediate points by strong steel-wire lashings. The object of the rows of poles is twofold; first, they prevent the stone from slipping off the mat when it is sunk on a steep slope; and, second, by being lashed to the body of the mattress by noncorrosive wire they prevent the displacement of the brush after the steel-wire weaving strand and all other corrosive connections shall have rusted away. At the outstream edge of the mat the poles are cribbed up two deep to better insure against the tripping of the stone when the mat is sunk or when it is subsequently undermined by scour at its edge.

The construction of this mattress, at first slow, developed during the season a rate of progress far exceeding expectations. At Ashport Bend six mattresses 300 feet wide were constructed. The average number of linear feet constructed per day with the first mat was 74.6; second mat, 82.2; third mat, 101.4; fourth mat, 92; fifth mat, 102.3; sixth mat, 109.5. The greatest progress on any one day was 160 feet with 246⅔ days' labor. At Hopefield Bend four mats, 310 feet wide, were constructed, with the following progress: First mattress, average per day, 93 linear feet; second mat, 127 feet; third mat, 140 feet; fourth mat, 153 feet. The greatest progress per day was 175 feet with 342 days' labor. The best progress per day with the Bullerton mattresses, 250 feet wide, was 200 linear feet with 212 days' labor.

The ballasting and sinking of these mattresses have been attended by no special difficulty, but the operations are necessarily more systematic and deliberate than with the old style of mattress, on account of the former's greater weight, density, and flexibility. In ballasting, it is necessary to do the work rapidly and sink the mattress immediately afterwards. This precaution is made necessary by the great compactness of the brush fascines and the rapidity with which they accumulate sediment after they have been pressed under water by the ballast. So rapidly do they accumulate sediment that if there is any considerable delay in ballasting, portions of the mattress on which the ballast may be a little excessive may be carried below the surface of the water by the weight of the accumulated deposit before all is ready for sinking. The mats were sunk in the same manner as the old type of mats were sunk, but the operation was much more deliberate and systematic. Toward the close of the season's work the foremen of the different parties had become so well drilled in their respective duties that a large mattress could be sunk

with scarcely a word of command, all necessary directions, which were few in number, being communicated as far as possible by signals well understood by all.

In the construction of 1,000 linear feet of mattress 300 feet wide, the following material was used:

Brush	cords	446.1
Poles	do	122.4
Stone	cubic yards	2,741.4
Iron wire	pounds	14,565
Silicon bronze wire	do	1,893
One-fourth-inch wire strand	do	12,348
Five-sixteenths-inch wire strand	do	6,600
One-half-inch wire strand	do	9,960
Staples	do	558
Clamps	number	3,696
Piling	feet	243
Rope	pounds	498

Brush not exceeding 3 inches in diameter at the butt makes a fascine of uniform strength, thickness, and compactness. This limit of size was preferred, but as the brush bars within a considerable distance of the works had been very much depleted in former season's work, brush as large as 4 inches at the butt was accepted, and, at times, even larger brush was taken to avoid embarrassing and expensive delays. The one-half and five-sixteenths inch strands included in the above bill of material are used for the bottom longitudinal strands, the one-half-inch size being used at the channel edge of the mat, where the current is greatest, and the five-sixteenths-inch nearest the shore. Smaller strands than these were used in a few of the mats when the supply of the larger strands fell short, but in such cases additional longitudinal strands were stretched over the top of the mat after it was completed, and clamped at intervals of 10 feet to the weaving strand in the same manner as the latter was clamped to the bottom longitudinal cable. The one-fourth inch strand is used exclusively for weaving. Two forms of clamps have been used, the "Crosby" and a homemade clamp. Both are shown in detail in Plate 10. Various forms of staples have been used. A staple of the fence-wire type, 1¾ inches by six-sixteenths inch, made of No. 9 wire, is a good, cheap, and suitable form of staple. Stone not exceeding 35 pounds in weight was preferred in both ballasting and sinking. Much of the stone which was stored on the bank for the season's work had been contracted for before the fascine type of mattress had been approved, and all of it which exceeded the 35-pound limit was reduced to the proper size by sledging. The application of the other materials mentioned has been previously explained.

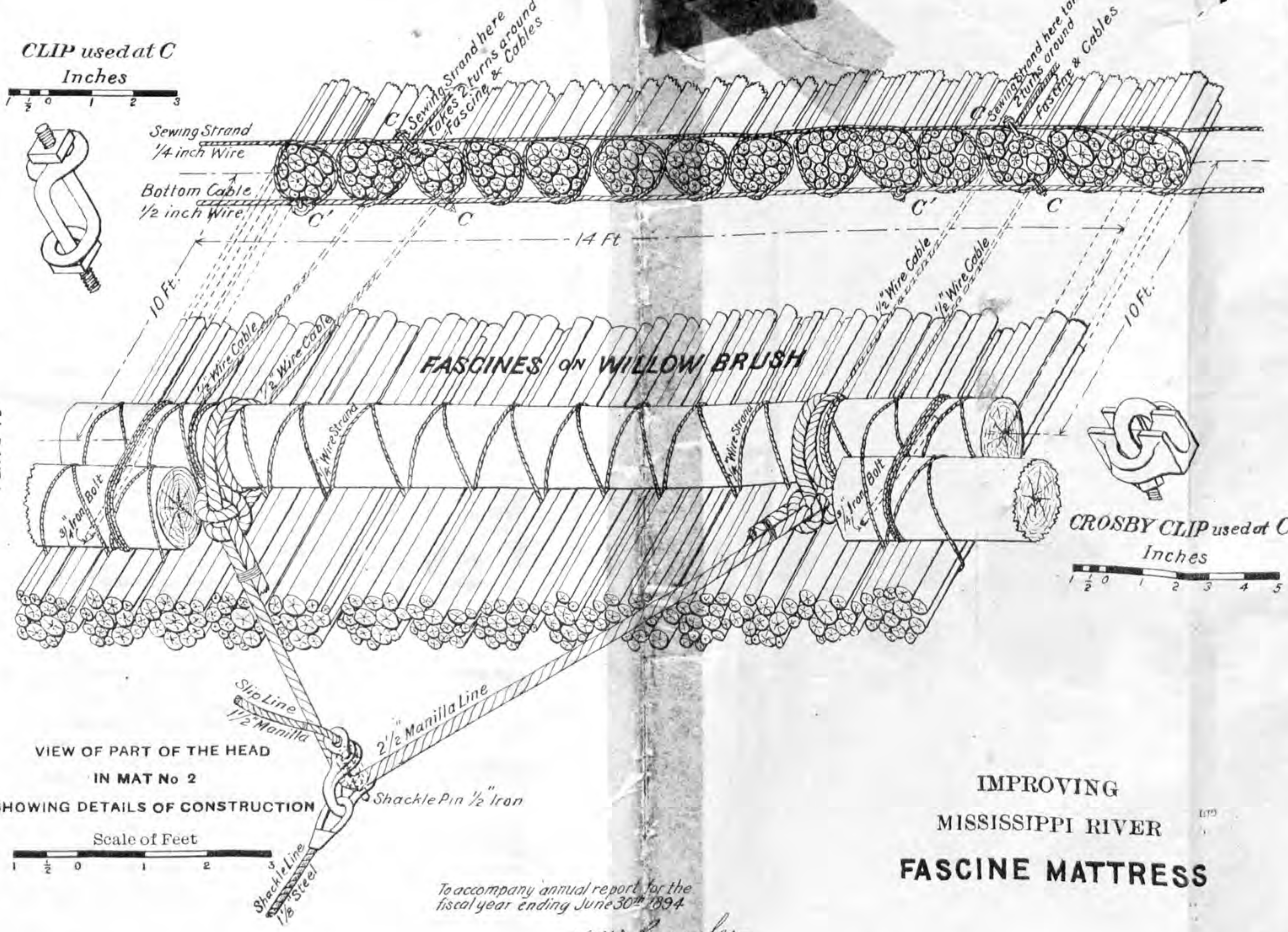
The mattress here described is believed to fulfill more perfectly than the old type of woven mattress the conditions which are essential in the subaqueous portion of the bank's protection. These conditions are:

(1) The mattress must prevent the material of the bank from being eroded by the attack of the current through the body of the mattress.

(2) It must prevent the material under the mat from being washed out through it by the return flow of water from a saturated stratum of the bank when the river is on a falling stage.

(3) It must possess enough flexibility to follow rapidly and without danger of rupture the scour which takes place at the channel edge of the mattress for several years after its construction and until the mat has reached its permanent bed.

PLATE 10



VIEW OF PART OF THE HEAD
IN MAT No 2
SHOWING DETAILS OF CONSTRUCTION

Scale of Feet

1 ½ 0 1 2 3

IMPROVING
MISSISSIPPI RIVER
FASCINE MATTRESS

To accompany annual report for the fiscal year ending June 30th 1894

S. W. Roessler
Captain of Eng'rs

Drawn by R. C. Hoyer.

Traced by H.d'A.

(4) When the scour at the channel edge of the revetment has reached its ultimate development and the mattress has reached a permanent bed, the mattress itself must possess the element of long life or permanency.

The compactness with which the brush is laid in the fascine mattress and the thickness of the mattress itself, which approximates 1 foot, afford ample security against the attack of the current upon the bank through the body of the mattress, and the flexibility which this mattress possesses will permit it to follow, without danger of rupture, any scour which may take place at its edge. The only two questions in doubt are those expressed in the second and fourth conditions. Whether or not the mattress as constructed possesses enough compactness to prevent the transport of material through it by the return flow of water from a saturated stratum of bank only time can tell, but there can be no doubt that in this particular, whether it fail or not, the fascine mattress possesses very great advantages over the old style of mattress in which the brush was woven more or less loosely in a single layer. As regards the question of permanence, two factors are relied upon to fulfill this condition. The first is the riprap distributed over the mattress in ballasting and sinking. As the fascine mattress contains 50 per cent more brush than the old woven type, the quantity of stone required to ballast and sink a given area is proportionately greater. The stone being also of small size, the amount distributed over the mat in the process of ballasting alone is sufficient to form an almost continuous pavement of stone blocks over the whole length and breadth of the mattress. If, when the mattress is sunk, and subsequently when the mattress follows the scour at its edge, the stone does not slip down the slope, the original ballast, together with the additional quantity added in the process of sinking, will form so continuous a layer or paving of stone as to prevent the displacement of the brush even after the weaving strands and all other perishable connections are rusted away. As an additional precaution against the displacement of the brush when the steel strand shall have rusted off, the longitudinal rows of poles, which are 16 feet apart, are lashed to the body of the mattress by a noncorrosive wire, which shall permanently hold the pole system intact and prevent the displacement of any brush when the ballast may from any cause become unevenly distributed. The mattress is open to the criticism that all of its longitudinal connections are of a perishable nature, but events may prove that this objection is more fancied than real. The function of the longitudinal fastenings is to tie the mat together longitudinally, to hold it together until it is on the bottom and until all the scour that will probably take place at its edge has taken place and the mat has reached its permanent bed. This done, the steel-wire strands have performed all the functions they were designed for and all they can perform, and permanence thereafter will depend upon the stone ballast and the noncorrosive lashings on the longitudinal poles, and, if these prove effectual in preventing the displacement of brush after the steel wires have rusted away, the objection to the use of a perishable material in the weaving of the fascines into a mattress will be overcome.

Fascine mattress with the fascines placed parallel to the bank.—The oblique position of the mattress-head cables to the head of the mattress in the form of construction just described exerts a strong shore thrust on the mat head in the process of sinking. This thrust is taken up by the strong mat head and the mat itself, which, together, have the requisite rigidity to withstand the thrust without danger of doubling up. Owing to the very much greater lateral flexibility of the mattress in which the fascines are parallel to the bank, it was not deemed safe to have any shore thrusts at all and the mooring arrangements

were accordingly modified. A set of mooring barges was anchored at the head of the mat in the usual way by mooring cables passing obliquely upstream to deadmen on shore. A second set of mooring barges was moored in the same way 800 feet above the lower set. On the deck of the upper barges was placed a continuous line of log deadmen, chained to the timberheads held by the shore cables. These deadmen were to hold the cables mooring the mattress and mattress plant. As the mattress was constructed its mooring cables were attached to it in the manner to be hereafter described, passed underneath the lower mooring barges, carried upstream parallel with the bank, and secured to the line of deadmen on the upper barges, thus avoiding any shore thrust upon the mat head. The mattress plant consisted of four mattress ways and their corresponding fascine barges, lashed end to end, giving a combined length of 588 feet. The barges were moored parallel to the bank and with the ways inclining toward the shore. The fascines were made 588 feet long, the full length of the mattress. The mattress was constructed by beginning at the water line and extending outstream until the full width of 250 feet was made. The details of construction were the same as those heretofore described for the mat in which the fascines are normal to the current. To give the mattress more longitudinal strength than the fascines themselves possessed, one-half and five-eighths inch strand, extending the whole length of the mat, were built into it in the following manner: When the construction reached the desired point the longitudinal strand was stretched across the bottom strands of the mattress and clamped to them at the points of intersection by common clamps. The upstream end of the strand was given two turns around the mattress head and carried back and clamped to itself at 130 feet. For additional security, the longitudinal strands were connected together by a diagonal system of backing-up straps 100 feet below the head of the mattress, as shown on Plate 8. The mattress head of this mat differed from previous construction, in that it was a kind of jointed spar designed to adjust to the bed of the river when sunk. This spar was made of 14 cypress logs about 12 inches in diameter and varying in length from 28 feet next to the shore to 14 feet on the outstream end, all put in place before launching from mattress boats. The logs were placed on top of the mattress and about 3 feet from the head of the mattress with laps of 2 feet. A three-fourths-inch drift bolt 2 feet long was driven horizontally through both logs at each lap, and in addition the logs were bound together by several turns of wire strand at the pin points. The logs were secured to the fascines by two wrappings of one-fourth-inch strand, and to every alternate log two of the longitudinal wire strands were made fast. Spanning these alternate logs 2-inch manila ropes were made fast at the same points, receiving the longitudinal strands. Each one of these rope loops formed an equilateral triangle, with its log for base, and with the shackles of its mattress mooring cable at the vertex. Parallel lines of poles 16 feet apart were wired to the mattress normal to the current and bank by lashings 5 feet apart, each alternate lashing being silicon bronze wire. The object of these poles was twofold: First, to give the mattress some stiffness, as without them it was feared the mat would be so flexible as to fold up in sinking; and, second, to give to the mattress an element of permanence by its noncorrosive wire lashings. Parallel rows of poles were also placed longitudinally to keep the rock from rolling off the mattress. The mattress was ballasted and sunk without incident worthy of special notice and under conditions more severe than the average. The river was on a rise, the current strong, and a considerable amount of drift was encountered. The experiment has demonstrated that mats of this description can be constructed and handled safely on a large scale if it should prove a better protection than the mattress with fascines placed normal to the current.

Review of bank protection work to 1896.—The following review of bank-protection work was made in the annual report of the Mississippi River Commission for 1896, pages 3419 to 3423:

In the preceding reports of the commission accounts have been given in greater or less detail from year to year of the construction, cost, and subsequent history of the various works for bank protection and channel contraction in the bed of the river, which have been built under the recommendation of the commission. One important result of experience in respect to these two kinds of channel work has been to emphasize more and more the relative importance of bank protection as compared with works for contracting the channel way by the upbuilding of new banks. It is now considered settled that in a plan for the permanent improvement of the channel by the contraction of its low-water width the work of bank protection should precede the permeable dikes and other structures of that class, and that the latter may be regarded as supplementary in function and as necessary only in a minority of cases. For several years past the amounts expended on such works have been relatively small.

The problem of bank protection has been found extremely difficult. The first mattresses made, although as large as it was at that time considered practicable to build and sink them, were found to be too small and too light for the wide bank slopes and heavy currents of the lower river. The first step toward their improvement was in the matter of size and strength. The width of the standard mat was progressively increased from 100 to 300 feet and its length from about 600 to 1,200 feet and over. These changes were made step by step as observations and results showed the necessity for them, and the improvement in the art of building and sinking them, which came as the result of experience, made them practicable.

Changes have been made also in the structure and texture of the mattresses with a view to a greater degree of flexibility without diminution of thickness or strength. It was found that when the attack of the river upon the bank was violent and persistent, and the mattress held its place unbroken and unmoved by such attack, there was a tendency to vertical scour along the foot of the mattress which, having extended downward a number of feet, was likely to eat back beneath the edge of the mattress and so undermine it. The best security against this danger is considered to be to impart such flexibility to the mattress that with the progress of any such course of undermining it will follow the recession of the bank at its lower edge before that extends to dangerous dimensions. It may help to a conception of the conditions under which work of this kind is done to say that in a typical caving bend on the lower river the channel may have a depth of from 50 to 80 feet at low water; to this a flood adds perhaps 40 feet, making from 90 to 120 feet in vertical height of erosible bank to be protected. The shore edge of the mattress is placed as nearly as possible at the low-water margin, and covers the subaqueous bank, which lies at various slopes, from 1 on 2 to 1 on 4. That portion of the bank extending above the low-water margin is graded to a slope of about 1 on 4, and covered with heavy riprap of broken stone. It has taken a long time and a large outlay of money to test so far the efficiency of various forms of mattress construction. There were conditions attending the work, seen now more clearly than they could be in advance, which made this unavoidable. When a revetment had been constructed of as perfect design as seemed at the time attainable within limits of practicable cost, many circumstances occurred to prevent any decisive proof of either its success or failure for a long time. The persistency and violence of the river's attack upon its

caving bends are variable and uncertain. It has happened repeatedly that upon the completion of an extensive revetment the attack upon it has moderated to such an extent that its subsequent continuance in place uninjured for years would throw no light on the general questions of construction and durability. It sometimes happens that a revetment fails from causes which can be seen clearly to be local or accidental. Such cases may point the way to avoid that particular disaster under the particular conditions there existing, but they are of slight value as steps in the solution of the general problem. Moreover, in the cases of the highest experimental value the lapse of considerable periods of time is a necessary element of the experiment. When a revetment of the best known construction, put upon a bank of the most difficult kind to hold, and subjected to the severest attacks, keeps its place unimpaired through one flood, the experience is encouraging so far. But it is only when the work has stood the test of flood after flood for a series of years that it can be pronounced a success. And when it is remembered that the success or failure of a single revetment at the end of one or a number of years is only a single experiment of many which must be tried, compared, and studied in order to lay the foundation for general deductions, it is evident why the progress of the work toward its final development, under the conditions which have existed, could not be otherwise than slow.

If the works for bank protection originally projected had proved sufficient, as it was hoped they might, to hold the banks of the river with permanence, a substantial improvement of the channel throughout the worst reaches of the lower river would have been possible by this time. When they failed to realize those expectations the problem became a new one. No precedents existed to throw any certain light upon it. It had to be taken up and worked out by original methods, experiments, and trials. As these proceeded, the necessary cost of the work increased, step by step. It was taken for granted that the disposition of Congress to undertake finally the permanent improvement of the entire river in this manner would depend in large degree upon the anticipated cost of the work, and that it was incumbent upon the commission to find out, if it could, not only whether or not the work is possible but the lowest cost at which it is possible. With this view the progressive changes in structure and methods which have been made have been conservative, proceeding by short steps as necessity seemed to require.

A point has been reached now at which some important facts can be definitely stated. While it is not possible to say that the form of bank protection employed in the last works of that kind constructed is incapable of improvement, it is undoubtedly much superior to that done in the earlier history of the work, and no promise of advantage by further change appears at this time. Another type of fascine mattress is constructed of very small flexible poles and brush made up first into long bundles and then woven with a wire warp into mats 300 feet wide and as long as may be desirable up to 1,200 feet and upward. With this form of mattress sunk and secured by the methods now employed, and sufficiently heavy upper bank riprap, it is believed to be possible to hold any caving bank on the river, barring extraordinary accidents or mishaps. But it costs, in round numbers, $30 per running foot of bank protected, which is two and a half times the cost originally estimated by the commission.

In situations where large interests depend upon holding a comparatively short line of bank, as at city harbors, points where cut-offs are threatened, or levees of exceptional importance are liable to be breached by caving, the efficiency of bank protection at a cost not incommensurate with the interests involved is a demonstrated fact.

Another fact of importance now definitely settled is that the construction of mattresses of the type now employed on a large scale the supply of material becomes an element of the problem presenting serious difficulty. The area of willow-producing bar necessary to supply material for a mile of fascine mattress 300 feet wide is probably five times as great as that required for an equal length of the mattresses built in the early years of the work. The quantity of small willow growth used in this form of mattress is so great that the estimated yearly supply available along the whole length of the river from Cairo to Vicksburg is not more than sufficient for the making of 15 miles per annum of bank revertment. This growth is renewed very rapidly, and the supply could be increased somewhat by artificial means. It is possible also that some artificially prepared material could be used in connection with the small willows in the construction of mattresses, as by splitting the larger willows, or perhaps other growth, into small flexible strips. But all such expedients would involve experiments not yet tried and would affect the item of cost in a degree which can not be foreseen.

There are methods of protecting caving banks besides the continuous-mattress revetment. Among these, that known as the spur-dike revetment is the best and most widely used. This form of revetment has been tried at some places on the lower Mississippi under the recommendation of the commission, the most important of these places being at the harbor of New Orleans. The spurs in all these revetments were constructed of brush mattresses and stone. But sawed lumber could be used in the place of brush; and of this the possible supply is ample. Some forms of spur have also been suggested, but not tried, involving the use of sawed lumber alone.

It is not to be doubted that there are some situations in which spur-dike revetments can be employed with success, but for use on the soft banks and in the rapid currents which characterize the greater part of the river between Cairo and Vicksburg the commission does not consider that form of bank protection as a safe and reliable one—certainly not one to be constructed on a large scale and at the hazard of great loss if it should fail—without some years of careful experimentation.

From all these facts together it became apparent several years ago—not all at once, but gradually, as facts accumulated and the deductions of experience were unfolded—that it was not possible by any or all of the methods which had been employed to accomplish such permanent improvement of the river from Cairo down as was necessary to meet the urgent demands of commerce within any reasonable time to come. It was this disagreeable, but unavoidable, conclusion from the work of preceding years, together with the recent and wonderful development of the hydraulic dredge, that led the commission to undertake the experiments of dredging the bars of the river with a view to the temporary improvement of its low-water channel. * * *

* * * It was recognized from the beginning of the commission's work that the construction of works of bank protection and channel contraction in detached reaches would be subject to influences more or less unfavorable from changes in unprotected bends above. In commencing work in the detached reaches of Plum Point and Lake Providence the commission was not oblivious of this fact, but was influenced by other considerations, which seemed to overbalance this disadvantage, and it has not since seen good reason to doubt the wisdom of that decision. But the experience gained in those reaches emphasizes the fact that it is highly important in any project for general and permanent bank protection to leave no unprotected reaches above the work done from changes in which new conditions may be produced in improved parts of

the river. And it is considered by the commission that in undertaking a complete and permanent system of bank protection the work ought to begin at the upper end of the river, at or near Cairo, and be carried thence downstream with substantial continuity. The distance from Cairo to Vicksburg is 600 miles. In a project for the complete and permanent improvement of that portion of the river, by the means stated, some portions of it would require work on both sides of the channel, though this would not usually be the case. And it may be that in some portions of it no work would be needed at all, at least for a number of years to come. As to these matters, an exact judgment can not be formed in advance.

Board mattresses in Bondurant Chute.—These mattresses were constructed as follows:

Ways, somewhat similar to those used for willow mattresses, were built at a convenient point. On these ways 1 by 12 inch by 20 foot boards were placed as close together as possible, in strakes 100 feet long, all joints being lapped. The strakes of boards were held together by strips of 2 by 4 inch lumber, running entirely across the mat at intervals of 4 feet, and at right angles to the boards. The boards were fastened to the 2 by 4 inch strips by two 4-inch steel wire nails, and one 3½-inch copper nail, this latter to give permanency. All nails were clenched. In order to provide against the ballast slipping off of the mat, short pieces of 2 by 4 inches were placed at right angles to the transverse pieces at intervals of 10 feet. After being launched from the ways the mats were floated to the locality where they were to be sunk and securely fastened to the bank. They were sunk in slack water in the following manner: The entire mat was ballasted until its bouyancy had almost been overcome. Then the inshore edge had additional ballast placed on it until it sank sufficiently to allow a small barge, loaded with concrete blocks, to be floated over it. This barge was gradually worked out over the mat and way from the bank, while ballast was thrown from it until the whole mattress was sunk in its place on the bottom. In this manner 30,000 square feet of board mattress were successfully sunk.

From August 6 to November 22, 1900, progress was slow, and the sudden rise of the river in the latter part of November created an emergency at this point. On November 29 but 30,000 square feet of board mattress were in place and there were 45,000 square feet afloat. While no difficulty had been experienced in placing and sinking the board mattresses in slack water, it was found impracticable to do anything with them in the swift current that commenced to run through the chute. On December 4, after several failures had been made with inadequate plant, the most skilled employees endeavored to sink one of the mattresses. It had been reinforced by additional strakes of 2 by 4 inch material placed on the upper surface to keep the ballast from shifting. When the attempt was made to sink the mattress, boils occasioned by the current forced portions of it to the surface until nearly all the ballast had been thrown off. It finally broke to pieces and floated away. Two other board mattresses broke loose from their moorings and floated down the river, and a third was beached on the sand bar opposite the revetment. The use of board mattresses was then abandoned and the work finished with the usual type of willow mattress. (Annual report of Mississippi River Commission for 1901, p. 341.)

By resolution of the commission dated June 26, 1907, the district officers were directed to take into consideration separately and in consultation as opportunity occurred, the subject of some other ma-

terial to be used in the place of or in connection with willow brush in the construction of mattress revetments, and among other things to consider the feasibility of the use of flexible strips made by splitting the trunks of small trees; and at any time when they shall have reached any conclusions on the subject to report the same to the commission.

Under date of April 9, 1908, Capt. William D. Connor, Corps of Engineers, United States Army, in charge of Mississippi River Commission districts Nos. 1 and 2, submitted the report given below:

In compliance with resolution of the Mississippi River Commission, dated November 22, 1907, I constructed a revetment mattress, using 2 by 2 inch strips from 12 to 16 feet long in place of willow brush. The following is my report thereon.

The mattress was made in all respects like a willow mattress, except that the fascines were made of seven 2 by 2 inch strips instead of using willow brush. The resulting fascines were about 9 inches in diameter in the mattress. The material used was gum, sycamore, elm, and other timber available, but mainly composed of these three kinds. The price of the lumber was $13.75 per thousand board feet. The fascines were built on the mattress barges because it was not found practicable to build the fascines on the bank prior to placing them in the mattress. The weight of the lumber was about 58 pounds per cubic foot, and although this weight was nearly that of fresh water it was thought that the resulting mattress would float, although it would set very low in the water. On launching the mattress from the ways it was found that it very soon sunk, and we were unable to build sections in such lengths as we were when using willows in the fascines.

We built two mattresses, one of which was 312 feet long and the other 270 feet long, but in each case the strain on the fingers of the mattress barges became so great when these lengths were completed that we were compelled to cut the mat off and sink the portion then built.

We were unable to pole the mattress as in case of a willow mattress, on account of its great weight, and the work of construction was therefore delayed every time that the ways were full, in order to do the necessary poling. This work, although not difficult, is usually done by special men, but in order to keep the entire gang at work everybody was put to work poling the mattress as soon as the ways were full. These men worked to considerable disadvantage through lack of experience and there was a resulting delay in the work that would not have been encountered had the mattress been light enough to permit the necessary poling after the mat was afloat.

Building the mattress in such short lengths involves in addition to the extra cost due to the above-mentioned delay, two other items of expense that would not have been encountered in a continuous mattress; the first of these is the cost of a 10-foot lap between the mats, and the second is the cost of building a new head for the second section of mat. The following is the cost in detail for the two mattresses as built:

2 by 2 inch lumber	$6,363.50
Labor and superintendence	4,165.75
Steamer *Graham*	847.50
Subsistence	910.00
Stone	959.63
One-fourth inch strand	573.57

Five-sixteenths inch strand	$173.94
One-half inch strand	567.00
No. 12 wire	145.38
Silicon bronze wire	151.39
Five-sixteenths inch clips	43.78
One-half inch clips	66.48
Staples	8.32
582 linear feet of mat, at $25.73	14,976.24

In the above table all except the first five items will be the same for the willow mat as they are for the timber mat. The item for lumber is considerably greater than the corresponding item for willows would be. The cost of the lumber per running foot of mat was about $11.69, and the cost of willows per running foot is about $4.38, taking the lumber at $13.75 per thousand and the brush at $1.28 per cord. This leaves a difference of $7.31 per foot that must be made up from the next four items on the list, in order to bring the cost of the timber mat down to the cost of a corresponding willow mat.

The amount of stone used on these timber mats is about one-half the amount that would be necessary upon a willow mat and this reduces the $7.31, mentioned above, by $1.64, leaving $5.67 per running foot of mat, which must be made up in rate of work. The cost of labor, subsistence, superintendence, and steamboat for the timber mattress is about $10.17 per linear foot for a mattress built at the rate of 0.9 of a linear foot per man per day. Assistant Engineer M. Gardner, who had charge of this work, says that with material that would float he knows he could make at least 1½ linear feet per man per day, and an examination of the daily operations convinces me of this. This would reduce the cost for these three items to $6.10 per linear foot, and the resulting mattress would then cost $1.20 per linear foot more than a willow mattress built under the same conditions. This difference in cost can be made up in the cost of the timber, for I have talked the matter over with mill men, and they say that if they could get out this lumber through the year they could deliver it at the present time for about $11 per thousand on barges, and this would be a saving of about $2.34 per linear foot in the material of which the fascines were made.

The above conclusions are based entirely on the supposition that we can get 2-inch strips that will float. To ascertain the weight of lumber, such as was used in these mattresses, when dry, and the amount of water it would absorb in a given time, I had samples of gum, sycamore, and cottonwood thoroughly dried and then immersed in water for a period of 12 days. The following table shows the results obtained in this test:

	Weight, dry, per board foot.	Absorption in 12 days.	Final weight.
	Ounces.	*Ounces.*	*Ounces.*
Sycamore No. 1	48.05	20.46	68.51
Sycamore No. 2	48.46	17.76	66.22
Gum No. 3	44.0	21.0	65.0
Gum No. 4	44.20	22.66	66.86
Cottonwood No. 5	41.27	20.73	62.0
Cottonwood No. 6	42.0	19.0	61.0

The heaviest sample tested weighed about 4.3 pounds per foot board measure after the 12 days immersion; the lightest sample weighed only 3.8 pounds per foot, giving an average of 4.05 pounds.

If material can be obtained and thoroughly seasoned, a timber mat can be built as cheaply as a willow mat. In order to give the strips time to season, the stuff must be cut throughout the year and stored on barges until used. Approximately 850,000 board feet of lumber will be required for every 1,000 feet of mat, and during an active working season we must count upon about 9,000 feet of revetment in case the revetment work is taken up as seriously in the future as the present outlook promises. This would mean about 7,650,000 board feet per annum. Our present barges will carry about 80,000 board feet piled loosely to permit the circulation of air. This would require 95 barges of our present type, which, of course, is out of the question. The only way to handle this material would be to build barges of the size used in towing lumber on the river, but even on these barges not more than 400,000 board feet could be piled openly to provide for proper ventilation, and even then I do not believe that the inside timber would be sufficiently dried to give the necessary buoyancy. The number of barges necessary for this purpose would be 19 or 20, and the original cost and yearly repairs makes this method impracticable.

The question of yearly supply of mattress material is therefore reduced to sawed willows or to willow brush. I have not had an opportunity to investigate the supply of large willows along the river bank since the close of the working season on account of high water. I will look up this subject during the low-water season and make a further report to the commission.

After studying this question for some time I believe that the cheapest solution of this question is to acquire land, if necessary, and grow willows, but the figures do not seem to show that even this is necessary at the present time. A willow bar covered with 3-inch willows yields about 35 cords of brush to the acre. There are about 3.9 cords of brush and poles in a linear foot of mat. A season's work of 9,000 linear feet of revetment would require about 35,100 cords of brush and poles. The season's supply for this amount of work is therefore only about 1,000 acres. After the willow has been cut over, it grows up from the stump to the size used in this revetment work in three years. Grown from the seed it attains the necessary growth in four years, but to be on the safe side let us assume that five years is necessary for the willow to reach the size to be used in revetment work. On the basis of 9,000 linear feet of revetment per year we must therefore have about 5,000 acres of river bars available for this purpose. There are approximately 40,000 acres of bars in this district, which are only suitable for this purpose. As these bars grow in height and become unsuitable for willows, other bars are forming in the river, and it does not seem as though the question of willow supply in this district would become a vital one in mattress construction until the work increases far beyond what we now anticipate, and, from the experience with the timber mattresses and the foregoing figures in mind, I recommend that no further experiments be tried with timber mattresses, unless it be found that there is enough suitable willow of large size that can be cut up for this purpose.

In the meantime I recommend that each district officer have his survey party make an estimate, during their next season's work, of the willow bars in his district, giving the approximate area of each and such other information in regard to depth of water adjacent, character of ground, over which the willows have to be hauled, and stage of water at which the ground will be overflowed, and also the same information with regard to willow bars on which the willow is too large for mattress purposes without being sawed.

Sinking mattresses.—In 1884–85 owing to lack of stone a barge load of brick was distributed over a mattress in Bullerton Chute,

without accomplishing much good. The bricks were badly baked and soon crumbled in the water. The specific gravity being low a large number of them were required to sink a mat, and as the bricks were badly broken up and the mat not closely woven, the bulk of them passed through the mattress. It was estimated that $1 worth of stone would accomplish as much as $6 worth of brick under the most favorable conditions. During the fiscal year 1899 brick was used as ballast in sinking mattresses and cribs at spurs Nos. 12 to 17, inclusive, on the bank between Gouldsboro (967 L) and Algiers Point (969 L) in New Orleans Harbor. In February, 1915, the fourth district officer reported that every mat sunk with brick was still in place.

Concrete blocks.—The manufacture of concrete blocks for sinking mattresses was undertaken in the fourth Mississippi River Commission district in 1899 for the following reason:

Much difficulty has been experienced in this district in getting a reliable and economical supply of ballast for sinking mats. The contract price of rock has varied from $1.60 to $2.10 per ton, but deliveries have been so uncertain that it has been necessary in the general case to make rock contracts a year in advance and store the rock on the bank somewhere near the work in order that it may be available when needed. When to the contract price is added the cost of towing the rock to the storage ground, the cost of unloading it and piling it on the bank, the cost of again loading it on the barge and towing it to the point where it is needed, it is probable that the rock delivered at the work ready for use is not less than $2.50 per ton. It is difficult to tell the exact cost, because it is not practicable to compute accurately the cost of towing when the towboats are not employed steadily but are used also for other work.

To meet this difficulty experiments were made this season in making an exceedingly cheap grade of concrete, using the least possible amount of Portland cement to consolidate sufficiently well for the purpose the sand and gravel which lie mixed together on some of the river bars in the district.

About 10,311 tons of this ballast were made during the year at a cost of $1.63 per ton on the bar.

The report of Assistant Engineer A. F. Woolley, herewith, describes the methods used in detail:

The mixer, engine, and boiler were mounted on two tramcar trucks, these two cars being coupled together. There was another or third car, which was used as a batch or measuring car, and into this car sand and gravel was placed in the quantity necessary for one barrel of cement, at the proportions which were being used.

The concrete was formed or molded into blocks or slabs by parallel lines of 12-inch boards placed on edge and spaced 6 feet apart. These boards carried 1 by 2 by 12 inch vertical cleats on their inner faces, these cleats being spaced about 8 inches center to center, or 6 inches in the clear. These cleats supported and held in place plates of No. 12 iron, 12 inches by 6 feet, flanged on one edge 2 inches, so as to form a 2 by 10 inch angle, the 2-inch leg resting on the sideboard cleats and the 10-inch leg hanging vertical and forming the division between the adjacent blocks of concrete. These plates were used double; that is, one being suspended on each side of each cleat, thus forming a space of 2 inches between adjacent blocks of concrete.

The side or molding boards were held in place by iron clamps or dogs, 6 feet 4 inches long, terminating in a right angle, and a leg 8 inches long on each end. This 8-inch leg served to hold the boards from springing apart while concrete was being tamped, and also to hold themselves vertical by the weight of the 8-inch legs when the molds were being set up.

It will be seen from the foregoing that the ground formed the bottom of the mold. A light and portable track was laid parallel with this line of molds. The mixer was 12 feet long and was mounted crosswise on the truck so as to deliver well over into the center of the line of molds. The batch or measuring car was filled, the material was then shoveled directly to the mixer, thence delivered by the mixer direct to the center of the molds. There it was well tamped and left undisturbed for at least several hours before the molds were removed. The batch or measuring car was operated in such a way that by the time a batch had been shoveled into the mixer another set of men had filled the car with the necessary sand and gravel; this was leveled off and another barrel of cement spread over it and a fresh batch was ready for the mixer in a very short interval. After passing each batch through the mixer, the mixer and batch car were moved ahead just so many mold spaces as one batch would fill, thus limiting the amount of shoveling that would be necessary to thoroughly fill each mold.

In this way the work is continued as far as it is desired to carry the line of molds. In the meantime there is a force behind setting a new line of molds parallel to the previous one and shifting the track to a new position. Then the mixer and batch car are rolled back to the end of the new line of molds as before and the process continued, the limit being the territory covered by good material, or the area, otherwise the yard, over which it is desired to place the finished product.

Molding.—The plan for molding originally contemplated making the blocks of concrete 6 by 12 by 12 inches. This was to be accomplished by placing the 6-foot division plates 12 inches apart, and then subdividing further by using 12 by 12 inch plates placed at right angles between the 6-foot plates and spaced 6 inches apart, thus making 12 blocks between each of the 6-inch steel plates. This was impracticable owing to the additional labor of setting molds, difficulty of holding the small plates in place, difficulty of properly tamping the small blocks and removing the small plates. It was found advisable to place the 6-foot division sheets only 6 inches apart in the clear and to subdivide these 6-inch by 12-inch by 6-foot blocks by breaking with a sledge hammer into as many pieces as desired; this was done and included as a part of the process of loading, two men being able to break 150 to 200 tons per day, at a cost of say \$0.016 to \$0.02 per ton.

The side molding boards were unclamped at the end of one to two hours. This allowed the division plates to press together slightly, the air to circulate freely in the space between adjacent blocks, thus shortening the period at which the steel plates could be safely removed and reset in a new line of molds. Practically, I had often to remove these steel plates at the end of two hours, owing to the limited number at hand; this is entirely too early and results in considerable breakage of the green or fresh blocks. There should be enough of these plates at hand so that they would not have to be removed sooner than six or eight hours. Such a number was not procured this season because of the fact that there was a probability that after a season's work it would be demonstrated that a modification of the plant would be not only advisable but imperative from the point of view of greater economy of operation.

In 1900 and 1901 the plant was improved and concrete was made aboard barges at a cost of $1.79 per ton despite the fact that the plant was often tied up for lack of barges. The cost of those delays had to be absorbed in the cost of the concrete made. The report for 1902 made the year's work absorb most of the cost of plant. The same system was followed when the plant was increased and improved in 1902 and 1903. The costs per ton were given as follows: 1901, total cost, $2; 1902, total cost, $1.90; 1903, total cost, $2.03. The work was discontinued in 1904 by the district engineer without any explanation as to the reasons therefor. An investigation of the cause of the loss of the mats sunk with concrete ballast revealed the fact that there was a shortage of ballast at the time and an attempt was made to sink the mats without sufficient ballast. The experiments demonstrated that mats sunk with concrete are as effective as those sunk with stone, and that when the aggregate can be obtained at a moderate price the cost of concrete ballast is less than that of stone.

Sinking fascine mattresses.—When the mat is ready for ballasting, barges loaded with stone are placed along its outer edge. Planks are run out from the barges to and across the mat, and stone is carried out by wheelbarrows, distributing the weight on the mat uniformly until it is barely afloat. The ballasting is begun at the head and continued downstream, the barges being dropped down along the mat as each section is ballasted. Stone is also placed on the mooring barges along their downstream edge for use when the mat is being lowered at the commencement of the sinking.

After the ballasting is completed the mat is pulled close in to the shore and loaded stone barges, lashed end to end, having a combined length sufficient to cover the width of the mat, are hung from the mooring barges along the upper outside edge of the mat. Stone from the mooring barges is cast onto the mat near its head, and by slacking the slip lines the head of the mat is allowed to sink a few feet. The stone barges are then pulled in over the mat alongside the mooring barges, and long lines are passed from the mooring barges to the stone barges to control the movements of the latter. When all preparations have been completed a large force of men is placed along both sides of the stone barges, stone is cast on the mat, the slip lines are slackened, and the mat is gradually lowered to the bottom. The drop lines to the stone barges are then payed out, and the stone barges are permitted to drift downstream over the mattress, the laborers throwing off stones from all sides as rapidly as possible, until the mat is completely sunk. Under favorable conditions the time of sinking is less than an hour for a thousand-foot mat, counting from the time of sinking the mat head. A steamer attached to the outer end of the outstream stone barge and a line to men on shore

from the shore end of the inner barge control the barge from swinging too far in either direction. After dropping the stone barges over the entire length of the mat and sinking the latter it is usual to bring them back to the mooring barges and repeat the operation, this time permitting them to drift slowly over the mat and casting off the stone so as to secure as uniform a distribution as practicable and to insure the mat's being well down.

Plant.—The floating plant needed in the construction of the present standard type of bank revetment consists of mooring barges, mat barges, fascine barges, brush and stone barges, drift fender barges (needed at times), hydraulic grader and pile driver, towboats, quarter and store boats, etc.

Mooring barges are placed at the head of the mattress to hold it in position and keep off drift during construction and to aid in sinking. Ordinary decked barges are used for this purpose; they are strengthened by bolting their sides together with numerous iron rods and adding the necessary timber heads for attaching the lines and cables. A large capstan and two strong kevels are also needed on each barge. The barges in use are 120 feet by 30 feet, two or three of them being placed end to end, so that the combined length will be fully equal to the width of the mattress. To keep drift from getting under the mattress during construction it is the usual practice to hang chains, arranged in festoons, from the upstream side of the mooring barges. Two chains are used, extending along the barges and drawn up with rope straps and fastened to alternate timber heads. The chain used is generally of one-half-inch diameter iron.

Mat barges are fitted at 8-foot intervals with transverse ways, having an inclination of 1 on 4 and extending beyond the upstream side of the barges down nearly to the water surface. At their tops the ways end about 5 feet inside of the downstream side of the barge to allow for a working platform built at a convenient height. Under this platform, and at the end of each way, there is located a drum controlled by a brake and containing the wire strand used in the mattress. This strand passes from the drum up and around a sheave at the head of each way and thence down along the inclined way to the mattress under construction. By a proper manipulation of the drum brake the strand can be payed out where necessary, as in making a launch, and the requisite tension on it can be maintained. The drums used are those on which the strand is received as it comes from the factory and no rewinding is required. Near the top of each way there is bolted an iron "former." This is made of flat bar iron, shaped like the letter Y, one leg lying parallel to the way and the other perpendicular to it, both pointing upward, while the third and largest leg extends downward vertically

and forms a lever handle; the two upper legs are 18 inches long and the lower leg about 3 feet. The "former" is secured to the way by a loose bolt at the intersection of the legs. In it the fascines are constructed, and by lifting the lever leg they are thrown out and down the way.

Fascine barges are fitted with an upper deck or platform on a level with the working platform of the mat barges. They are placed downstream from the mat barges and parallel to them and are used to supply working room for handling the brush used in building the fascines. A revolving crane is now used to pass willows from the brush barges to the mat barge. Along the lower sides of the fascine barges the brush barges are lashed, usually so that the butts of the brush point upstream.

Brush and stone barges are ordinary deck barges, and are used to bring the brush and stone to the work.

Drift fender barges are sometimes anchored some distance above the mooring barges for the sole purpose of catching the drift flow where much drift is running. These barges have their own mooring ropes and drift-catching chains and extend far enough out into the river to thoroughly shield the mattress below. When the drift barges are used the mooring cables from the mat are anchored to them and a straight up and downstream lead is thus obtained. This is of considerable advantage in controlling the mat while it is being sunk.

UPPER BANK PROTECTION.

At first the revetment work consisted of a mattress below low water only. Experience soon showed that caving above the low-water mat would take place at high water and that protection of the upper bank was necessary. Generally the upper bank along a caving shore is steep and must be graded before it can be revetted.

Grading.—After sinking the mattresses the bank was graded to a slope of from 2½ to 3 on 1 in the early part of the commission work. In later work the slope was changed to from 3 to 4 on 1. The bank was usually graded by the hydraulic method.

The hydraulic grader is simply a boat containing the pumps necessary for the hydraulic grading. Pumps of various designs have been employed, and, in general, to be efficient the machine must be able to supply at least two streams discharging through 150 feet of 3-inch hose and 1-inch nozzles, maintaining a pump pressure of about 160 pounds per square inch. As one cluster of piles is usually necessary as an abutment for the mooring barges, it has been found convenient to have one end of the grader made into a pile driver. This makes the mat plant independent and is a convenient arrangement, as the pumps can furnish the jets for the pile driver.

The following is a description of the plant and the method of operating, furnished by Assistant Engineer Henry Steubing, who had charge of grading at Lake Providence Reach in 1883:

Description of plant.—The plant consists of two large pumps placed on barges 110 by 30 feet, 6-foot hold, on the deck of which are the machinery and boilers. A cabin is erected above the boilers and machinery which contains sleeping room for 30 men. The machinery of *No. 1* consists of a double-acting duplex plunger pump; that is, two pumps which are so constructed that the plunger of one pump moves the steam valve of the other, and vice versa. On *No. 3* the pumps work single. Each of these engines is compound. The 18-inch initial steam cylinders exhaust into an auxiliary steam cylinder of 36 inches diameter. Out of this the steam is exhausted into a condenser by an air pump, which at the same time pumps water into the condenser. The water is heated by this condensed steam to a temperature of about 100° and, passing from the condenser into a well, is used to supply the boiler. The stroke of the main pump varies according to the water pressure required; the maximum is 24 inches. The plungers are 16 inches in diameter. Besides these pumps, which are required for the grading proper, each of the graders has an engine for hoisting the boom pipe and stages; also a steam capstan. The hoisting engine is located forward of the main pumps between the legs of the shears; the capstan is placed at the other end to facilitate the handling of the boat. There are three 5-flue boilers on each grader 42 inches diameter and 22 feet long. On *No. 1* the boilers are of steel, and on *No. 3* of iron, both of 60,000 pounds tensile strength. They were tested for a steam pressure of 125 pounds. They are supplemented by an upright auxiliary boiler for cleaning and pumping up main boilers. In front of the furnace is the coal box, with storage room for 500 bushels of coal. The water to supply each of the main pumps is taken from a well in the bottom of the boat 3 by 3 feet, one on each side, through a 12-inch pipe. The bottom of the well is covered by a strainer made of three-eighths inch flange iron. This strainer has 2,500 holes of three-eighths inch diameter, which gives nearly two and a half times the area of the suction pipe. The water is discharged through two 12-inch pipes, one from each pump, into the main pipe, to which the boom pipe is connected, the joints so arranged where the pipes come together as to allow the boom pipe to have motion, both perpendicular and horizontal. The length of the boom pipe is 65 feet, tapering from 12 inches to 8 inches, and consists of four flanged pieces, which are bolted together. These pieces of the boom pipe are lap-welded tubes screwed into cast-iron flanges and bolted through flange and screw end of tube. The whole is stiffened by two hogchains, one below extending along the whole length, the upper one on top of the two smallest pieces, to which is attached the hoisting rope. The hoisting rope is 1-inch steel wire leading over a pulley on top of the shears, thence to the drum of the hoisting engine. The shears are pine timber, 54 feet long, 12 by 12 inches, the heels butting in iron shores on deck in a line with the hoisting engine. They are slightly inclined forward and are held by two 1½-inch wire-rope guys, which are fastened to the gunwales. The pumps have a capacity to discharge 2,000 gallons a minute under a pump pressure of 160 pounds.

Method of operating.—The grader is placed in position with one end next the bank, and the stage and boom pipe lowered so as to almost rest on the ground. When the bank is perpendicular a trench is first cut at the proper slope so as to give a face to begin grading. When a steam pressure of 80 pounds, giving an efficient water pressure in the pumps of 140 pounds, is

obtained, the work of grading is begun. A piece of 2-inch gas pipe, about 4 feet long and pointed at one end, is driven into the ground about 10 or 15 feet from the face and a little above the middle of the slope. The upper end of this gas pipe is allowed to remain from 10 to 12 inches above the ground; a piece of iron is fitted into the top of this pipe, to support the nozzle, with holes on each side, into which trunnions on the nozzle fit, so as to admit of motion in any direction. After the nozzle has been fastened in this swivel and the hose connected with the boom pipe at one of the valves, which are placed at intervals along the pipe for this purpose, two men take hold of the nozzle by means of a lever which is fastened to it by clamps, and the signal is given to turn on the water; three or four men are kept ready to lighten up the hose so as to enable the nozzle men to point the nozzle in any required direction. The stream issuing from the nozzle is directed against the bottom of the face to undermine it to a depth of from 6 to 12 inches, and in doing this is moved along the whole length of the slope. The earth that has caved through this undermining is then washed into the river. The quickest way to do this is to soak the whole of the loose material first and then direct the stream so as to carry this saturated material into the river, pushing it down by the force of the stream. In undermining it is always best to commence at the bottom and move upward. If the bank is more than 14 feet high, two nozzles can be worked with advantage. Where one nozzle is used 11 men are required, while for two, three additional men are needed. The force to run one grader requires 1 foreman, 2 engineers, 1 fireman, 1 greaser, 2 nozzle men, and 4 laborers; total, 11 men. With two nozzles working 15 men are required. A 1¼ or 1½ inch nozzle is then put very near the top of the slope and undermines the upper one-third of the face, while the 2-inch nozzle does the same with the lower two-thirds, and washes all of the caved material into the river. After the bank has been caved and washed down as far as from 30 to 35 feet from the nozzle this is moved 10 to 15 feet again. In doing this the water is shut off from the hose and is wasted through one of the other valves. The difference in the quality of the material that has to be undermined or cut into, the various positions in which the different strata are found underlying each other, height of bank, etc., requires, besides this general method employed, various modifications in special cases of managing the nozzle that can hardly be described and can be learned only by experience. This is well demonstrated by the cost of grading.

While grader No. 1 was at Delta Point, opposite Vicksburg, in November and December of 1882, the cost for grading for the first two weeks was 9 cents, from November 20 to 30, 6 cents. In December No. 1 excavated 39,000 cubic yards at an actual cost of 3½ cents. Grader No. 3 had in the meantime excavated at Mayersville Island 15,000 cubic yards, at a cost of 2⅜ cents, the bank consisting entirely of sand, while at Delta it was to a great extent intermixed with strata of hard clay, the different strata lying in unfavorable position for rapid work. In January, 1883, Nos. 1 and 3 together excavated on Mayersville Island 78,000 cubic yards, at a cost of 3⅓ cents, or, deducting all time lost through inclemency of the weather, etc., of 2.8 cents.

The following description of hydraulic grader No. 5, built in the fourth Mississippi River Commission district, is taken from the annual report of the Mississippi River Commission for 1901, page 353:

One of the new creosoted barges, *No. 12*, was taken as a hull and was extensively reinforced by keelsons, diagonal braces, stanchions, and truss rods to support the weight of the large pumps and boiler. The grader is equipped with

a Heine safety boiler and two compound surface condensing duplex pumping engines, with the necessary auxiliary machinery, such as air pumps and boiler feed pumps. The Heine safety boiler was installed by the builders and is generally described as follows: It is of 267 horsepower, with natural draft; has two shells 36 inches in diameter and 19 feet 4½ inches long; has two water legs, between which are 140 lap-welded boiler tubes, each 3½ inches in diameter and 16 feet long; has in each shell a patent submerged internal removable mud drum with blow-off. The boiler is set in a marine setting with ornamental fire front, complete, and has a smokestack 4 feet in diameter and 70 feet high. The main pumping engines are Worthington duplex compound surface condensing, of which there are two on the grader. Being duplicates, a description of one covers both. There are two high-pressure steam cylinders, each 12 inches in diameter; two low-pressure steam cylinders, each 20 inches in diameter; two double-acting water plungers, each 12 inches in diameter; all of 15-inch stroke. The low-pressure steam cylinders are steam jacketed, and both the high and low pressure steam cylinders are fitted with suitable dash relief valves to regulate the cushion and length of stroke of the engine. The steam valves are of the semirotative circular type. The water cylinders are of the latest design and have central outside packed plungers of cast iron. The steam and water cylinders are connected by heavy, rigid cast-iron frames, which prevent any liability of the engine getting out of line, making each machine "self-contained." The surface condenser of the latest improved design is located in the suction pipe. Common to both pumping engines is a large main heater; also one supplementary heater for utilizing the exhaust from all of the auxiliary pumps. There are two air pumps and two boiler feed pumps, steam, water, and vacuum gauges, engine counter, and the necessary wrenches, etc. All of the machinery is highly finished. The grader is also equipped with a 4½ kilowatt generator and is lighted with electricity throughout. There are also three arc lamps for use on shore when working at night. Briefly, hydraulic grader No. 5 is a most complete and satisfactory machine. While the boiler was installed under contract by the manufacturer, the pumping machinery, suction and discharge pipes, and all other connections were installed by day labor. That a good job was done in proven by the fact that not a day was lost from breakdowns during the entire season's work. The main pumps here described have each a capacity for delivering steadily 1,000 gallons of water per minute under a pressure of 175 pounds per square inch, with a piston speed not exceeding 100 feet per minute, while being operated with a boiler pressure of 150 pounds per square inch. The boiler and pumping engines are inclosed in a cabin 100 by 25 by 17 feet, and in this cabin or house are large and roomy quarters for a double crew. Grader No. 5 is quite different from Nos. 1, 2, 3, and 4 in many respects, among which may be mentioned that the suctions are not in a well, but are so arranged that they can be raised and lowered into the river on the side of the grader that is away from the bank. This also allows the baskets or strainers to be cleaned frequently. While not belonging strictly to the machinery of the grader, I would mention the use of ordinary piping connected with flexible joints as a substitute for the expensive and perishable rubber hose. Both graders No. 3 and No. 5 were equipped with 300 feet of 5-inch pipe in lengths of 20 feet, coupled together with the Moran universal coupler. The use of this pipe was in the nature of an experiment, but the results were entirely satisfactory, and with the exception of one or two lengths of 4-inch hose in the immediate vicinity of the face of the bank being graded the pipe was used exclusively and as a matter of preference by the grading crews.

During the fiscal year 1909 the third Mississippi River Commission district constructed a new hydraulic grader with a steam turbine and centrifugal turbine pump. This grader had much greater efficiency and was more economical than the direct-action plunger pump graders.

Paving.—The methods of upper bank protection were changed from time to time as experience developed the faults and suggested improvements in the types tried.

The following reports on upper bank protection were made in 1883:

In Hopefield Bend after the bank was graded to the proper slope, strong stakes were firmly driven in the ground, about 8 feet apart longitudinally and from 4 to 8 feet apart transversely to the bank. A No. 8 wire was then placed around the stakes longitudinally, their distance apart being 8 feet. Around this wire, at each stake, a No. 12 wire was placed and twisted around the stakes so that the ends could be had after brush was placed in position; this was to be used to tie the top and bottom wires together, thus holding the brush in place.

A layer of brush was now placed on the bank transversely, the butts up the bank and the tops overlapping the "deep-water mattress." On top of this a longitudinal layer was placed, and over all a No. 8 wire was stretched transversely, at every 8 feet; this was tied to the "deep-water mattress" and also to the bottom wire at each point of intersection. The whole was then well covered with stone. Whenever the "deep-water mattress" could not be joined to the upper bank revetment a foot mattress was built to cover the space. This was constructed on a small screen barge, and was similar to the large mattress already described.

In Lake Providence Reach a grillage of poles is first placed along the slope; on this grillage the brush is laid perpendicular to the direction of the current; another set of poles is laid on top of the brush over those underneath, to which they are fastened with wire to hold the brush in place. The poles are also fastened with wire to stakes driven in the slope, and the revetment covered with stone. On account of the scarcity of stone last season bags of sand were tried for the purpose of keeping the revetment in place, but they failed in accomplishing the desired result; they were easily torn, and the action of the current washed out the sand, rendering them useless for the object intended.

The lack of durability of the upper bank work was a source of trouble and the cause of some failures in the early revetment work under the commission. It had been expected that the upper protection work would silt up quickly and that the silt would protect the brush from decay. The upper bank brush quickly rotted, and the thin layer of stones did not prevent erosion of the bank.

On November 13, 1891, a resolution was passed by the commission—

That in the opinion of the commission brushwork should not, as a rule, be used in bank protection above low-water mark, but when the work is being carried on at stages of the river higher than the low-water stage, then a connecting mat may be placed covering the zone between the water surface at the

time and the low-water line; and that above low-water line the bank be graded to a slope or from one-third to one-fourth, according to material, and be covered with a layer of riprap about 10 inches thick, and that this revetment should extend to the height at which vegetation will flourish, and that above that height the growth of willows or Bermuda grass should be encouraged.

Under these instructions, in the usual method of paving, the riprap was laid on a 4-inch foundation of quarry spalls.

On November 20, 1883, the commission passed a resolution directing Capt. John G. D. Knight, Corps of Engineers, United States Army, in charge of the first district, to have 200,000 bricks made, to be used in upper bank protection, and authorizing him to continue the manufacture in case of good results. There is no record of the use of brick for this purpose before 1899.

On June 27, 1894, the commission directed the officer in charge of the third district to construct a kiln and make experiments in burning clay taken from the batture at various points in the district with a view to ascertaining the possibility of producing at low cost blocks of material of as large size as practicable, not exceeding 1 cubic foot, which would be able to resist disintegration in water, and of sufficient weight to answer as a protecting cover for caving banks; and to make experiments in the manufacture of blocks of sand concrete of low grade, using river sand with just sufficient cement to make a concrete that would not disintegrate under the action of flowing water.

Under date of March 6, 1895, the third district officer, reporting on his experiments, stated that—

The cheapest method to obtain burned lumps of clay for revetment work is to purchase standard brick by contract at $4 per thousand or $2 per cubic yard. A barrel of Louisville cement costs $1.15 in Memphis. Stone is costing $1 per cubic yard on barges at Pilchers Point. The sand found on Mississippi River bars is poorly adapted for concrete.

During the working season November 11, 1899, to February 25, 1900, a total of 230,500 square feet of upper bank was paved in the fourth district with five different kinds of paving, described by Assistant Engineer H. S. Douglas as follows:

First. Rock placed by hand in the usual way, with the voids filled with spalls, and averaging 10 inches in thickness.

Second. Concrete blocks averaging 8 inches in thickness. These blocks were manufactured on the gravel bar at the head of Bondurant Island, and their manufacture is described in the report of Mr. A. F. Woolley, jr., assistant engineer.

Third. Run of the kiln brick laid as follows: The area to be paved was divided into squares measuring 10 feet on a side by strips of 2 by 4 inch lumber laid on the flat. These squares were then filled in with brick laid on the flat and with their greatest length parallel to the bank line, care being taken to break joints with adjoining streaks. The bricks were laid in loose, a space of about one-half inch being left around each brick. Over this first layer of brick No. 10 galvanized wire was then stretched in such a way as to obtain a mesh 6 by

12 inches, the 12-inch dimension being measured parallel to the bank line. The wire was held in place by staples driven in the 2 by 4 inch strips, and it was so arranged that those wires that were parallel to the bank line should not be in lengths of over 50 feet, and that each 50 feet of pavement, measured parallel to the bank line, should not have continuous wires with the adjoining 50 feet. A cement mortar made of 1 part Portland cement to 3 parts of selected Mississippi River bar sand was then mixed, and with it a second layer of brick, each brick being precisely over each brick in the first layer, laid with the wire mesh in between. The joint made of the cement mortar was about three-eighths of an inch thick.

Fourth. Concrete in situ: The area to be paved was first divided off into squares measuring 5 feet on a side by strips of 2 by 4 inch lumber laid on the flat. The wire mesh was then constructed the same as for the brick. A second strip of 2 by 4 inches was then laid on top of the first. It will be seen that squares or molds 4 inches deep, with the wire mesh halfway between the bottom and top, were thus made. The squares were then filled with a hand-mixed concrete made of 1 part of Portland cement to 12 parts run-of-the-bar sand and gravel obtained from the gravel bar at the head of Kempe Chute.

Fifth. Concrete in situ the same as No. 4, laid without either the timber strips or wire, but 8 inches thick instead of 4. Only a small area was paved in this way as an experiment. * * *

The general scheme of upper bank pavement, which was adhered to as closely as circumstances permitted, was to divide the graded bank into three strips of nearly equal width from low-water mark to a height 18 feet below the high water of 1897, except where the top of the natural bank was below this grade. The lower strip was paved with either rock or concrete blocks. The middle strip laid with brick as described or with concrete blocks. The upper strip with concrete in situ 4 inches thick, in squares with wire mesh as described. * * *

In order to avoid a weak point in the general revetment, great care was taken in making the junction between the main mattress work and the upper bank pavement. Where the subaqueous mattress did not extend to the dry bank at the then existing stage of the river, either special mattresses were built to fit in the concave pockets or small mattresses, described for convenience on the work as ribbon mattresses, were built and sunk with their outer edge lapping on the main mattress, while their shore edge was on the dry bank, and from it the upper bank pavement was commenced. By this means there was a reasonable certainty that no uncovered bank remained between the subaqueous work and upper revetment.

In July, 1909, the officer in charge of the first and second districts was authorized to experiment on a small scale as to the feasibility of concrete paving reinforced with wire mesh, and submitted the following report:

At Hopefield Bend, Ark., February, 1910, the reinforcement used was wire fencing 55 inches wide, 6-inch mesh, top and bottom wires No. 9, and remainder No. 11 brass-wire gauge. The cement used was Lehigh, and sand and gravel was purchased from the Union Sand & Material Co., Memphis, just as it was pumped from the river. The proportions of concrete were 1 cement to 12 sand and gravel, this having been determined by experiment to give ample strength. The intention was to lay the concrete in strips 4 feet wide parallel to the river, and these strips to have a plane of weakness at intervals of 5 feet

blocks to be 4 inches thick. To accomplish this, strips 2 by 2 inches were laid on the graded bank at 5-foot intervals and perpendicular to the stream; the wire fencing was stretched over these, each strip overlapping the preceding one 6 inches; then 1 by 2 inch strips were placed over the 2 by 2 inch strips, larger dimension vertical. The concrete was then placed and the 1 by 2 inch strips were removed as the work progressed.

In Walnut Bend during the working season of 1910 the pavement, consisting of a concrete of 1 cement to 12 sand and gravel, was laid in strips 47 inches wide and 4 inches thick, extending from the edge of the mat to the top of the bank. The mixing was done with a Hains mixer, and the concrete was deposited on the bank by means of a derrick boat. It was spread with shovels and tamped. The reinforcement used was wire fencing 47 inches wide, 6-inch mesh; the longitudinal wires No. 9 and horizontal ones No. 11 brass-wire gauge. The cement used was Red Ring and the sand and gravel was purchased from the Union Sand & Material Co., Memphis, Tenn., just as it was pumped from the river.

On April 19, 1910, in order to secure further data as to the economy and efficiency of concrete bank paving in the first and second districts, the officer in charge thereof was authorized to use alternate stretches of stone and concrete, about 500 feet in length, in connection with such revetment work as might be authorized by the commission in the vicinity of Porter Lake, Ark., or elsewhere upon approval by the President.

Under these directions concrete upper-bank paving was placed at Golden Lake, Ark. (192 R), in 1912; at Sunflower, Miss. (355 L), in 1912, 1913, and 1914; at Trotters Landing, Miss. (304 L), in 1913; and at Star Landing, Miss. (257 L), in 1914. The cost of this concrete work was less than half that of stone pavement. The reinforcement was left out at Sunflower, Trotters, and Star Landing.

By resolution of the commission dated November 18, 1914, the district officers were directed to investigate the economy and efficiency of concrete as a substitute for stone in bank revetment work and report to the commission the results of such investigations, with recommendations relating thereto. The first and second districts officer, Maj. E. M. Markham, Corps of Engineers, recommended that 4-inch concrete upper-bank revetment be adopted as the standard for future work except in situations where, due to soft condition of bank, the necessity of providing for steamboat landings, or other suitable cause, stone paving be utilized. Maj. J. R. Slattery, Corps of Engineers, the third district officer, recommended that concrete paving of the upper bank be adopted as a substitute for riprap paving. Maj. W. G. Caples, Corps of Engineers, in charge of the fourth district, recommended that concrete paving be used from Warrenton, Miss. (609), to Baton Rouge, La. (833), and that stone be used below Baton Rouge until an economical substitute could be obtained and the work in sight was sufficient to justify the necessary investment for plant to manufacture and place the substitute.

By resolution of the commission dated April 15, 1915, the district officers were directed to use concrete for upper-bank paving in lieu of rock wherever such use could result in equal or greater efficiency and economy.

Since 1915 concrete has been extensively used for upper bank paving, the specified mixture being 1-2-3 and the thickness of paving 4 inches.

Reinforced concrete mattresses.—In October, 1914, Maj. E. M. Markham, Corps of Engineers, United States Army, presented to the commission some preliminary studies toward making experiments with concrete mats to replace willow fascine mats in subaqueous revetment in the first and second Mississippi River Commission districts. With an allotment of $2,500 made by the commission in October, 1914, for "experimental revetment" in the first and second districts, barges were prepared and eight 4-inch concrete slabs were formed and launched with such restraint as could be provided by lines handled manually. Five of these slabs were 14 feet by 18 feet 6 inches, two were 40 by 100 feet, and one was 19 feet by 48 feet 6 inches. These slabs were launched in from 10 to 40 feet of water. A diver employed to determine their condition found them intact and fully effective for revetment purposes.

The following report on experimental concrete revetment was made by Maj. E. M. Markham in June, 1916:

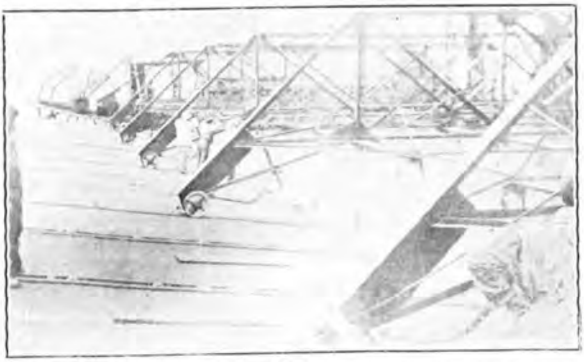
1. Based upon results accomplished under commission allotment of $2,500 for "experimental revetment," October 17, 1914, a further allotment of $25,000 was made April 18, 1915, for continuing the experimental work. The general proposition involved determination of the practicability of constructing an efficient and economical revetment by way of shingling caving banks with large sheets, or mats, of reinforced concrete, of such size, strength, and relation, one to the other, as to insure against destruction or displacement by the hydraulic forces to which subjected.

2. Sufficient progress is believed to have been made to justify conclusive report and recommendation. It should be stated that effort has been directed solely to establishing fundamental principles, the scale of the problem and the physical forces involved being such as to render advisable the commitment of substantial funds for appropriate plant, amply staunch to meet the conditions imposed by going work, before comprehensive revetment be undertaken. The scheme hereafter described will be observed to require unusual loading of the floating structure employed, which, accordingly, should be preferably in steel. Although in operations to date wood barges have been utilized, the latter are so likely to leakage or even collapse under radically eccentric burden as to render their use for actual field work somewhat hazardous.

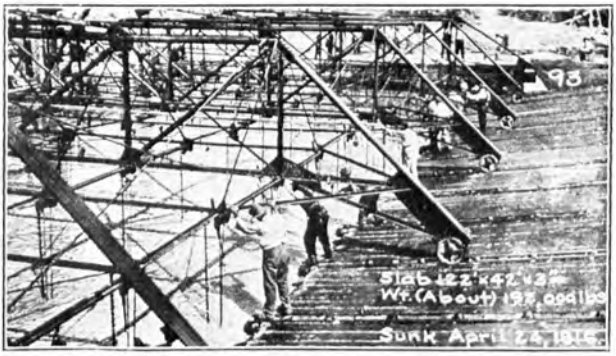
3. Several views are submitted from which a clear understanding of results to date may be had. (See plates Nos. 11 and 12.)

4. The experimental plant comprises two creosoted lumber mat barges upon which the concrete slabs are formed and a third barge upon which is mounted required machinery and structural work. The mat barges were built by day

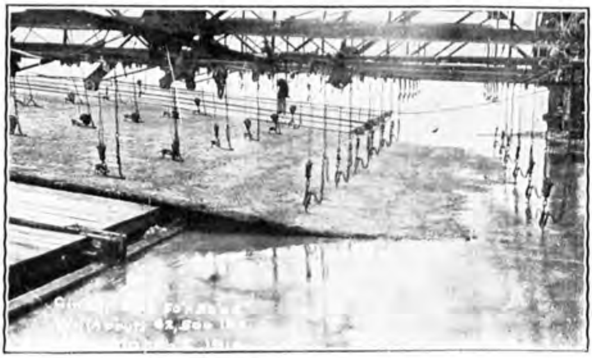
PLATE NO. 11.



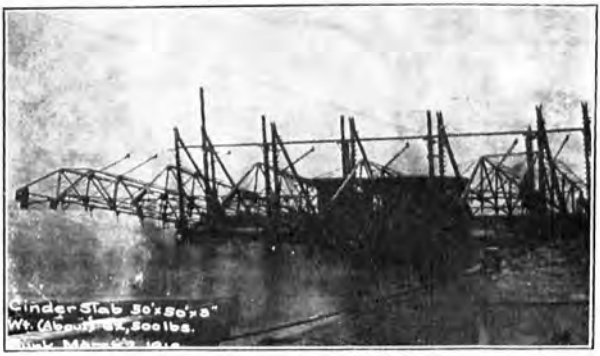
MONOLITHIC CONCRETE MAT SUPPORTED FROM OVERHEAD TRUSSES AFTER WITHDRAWAL OF MAT BARGE. BACK-HOLD LINES DISCONNECTED.



SLAB SUPPORTED BY OVERHEAD TRUSSES, WHOSE FREE ENDS, EQUIPPED WITH WHEEL BEARINGS, REST ON STEEL-SHOD WAYS OF MAT BARGE.

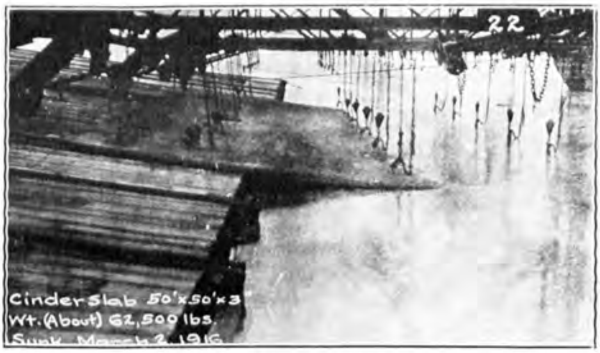


SLAB *IN PROCESS OF LAUNCHING; SUPPORTED IN* PART ON MOVABLE BUTTER BOARDS ON WAYS OF MAT BARGE AND IN PART BY SUSPENSION LINES, WHICH TAKE TENSION ONLY AFTER SUBMERGENCE OF MAT.



MOORING BARGE WITH HINGED TRUSSES. FREE ENDS OF TRUSSES REST ON WAYS OF MAT BARGE DURING LAUNCHING.

PLATE NO. 12.



DOWNSTREAM END OF SLAB LEAVING MAT BARGE.

BEGINNING OF LAUNCHING OPERATION. UPSTREAM SET OF SUSPENSION LINES IN TENSION; TRIP CHAINS WITH EQUAL SLACK.

PLATE NO. 12—CONTINUED.

BACK-HOLD LINES BETWEEN DOWNSTREAM END OF SLAB AND END POSTS OF TRUSSES PREVENT RACING.

LAUNCHING COMPLETED; SLAB SUSPENDED UNDER WATER PRIOR TO RELEASE OF SUSPENSION LINES. VIEW SHOWS ROLLERS UPON WHICH BUTTER BOARDS MOVE.

labor and the equipment secured from the Bucyrus Co., of South Milwaukee, Wis., who made several valuable suggestions respecting mechanical and structural details.

5. The thought of which the experiments herein outlined are believed to be a sufficient verification has been that sheets or mats of reinforced concrete of ample dimension for their intended purposes could be formed upon the inclined decks of barges and, after sufficient air hardening, successively launched therefrom by the withdrawal, under mechanical power, of the said barges, substitute support being simultaneously provided from a series of overhead trusses hinged upon a fixed mooring barge and having wheel bearings upon the ways of the barge withdrawn. During and after withdrawal this substitute support would be arranged for by a proper number, disposition and attachment of lines running from the overhead trusses to trigger or trip connection with rings or loops formed in the mat. A situation would thus be developed wherein the latter would be fully suspended between mooring and mat barges and thereafter might be lowered to position upon the supporting lines or tripped to freedom therefrom. After tripping, control and direction to position on the bed or bank to be revetted would be provided by shackle connections from the upstream edge of the mat to trolleys mounted upon mooring-barge spuds or by upstream and shore cables. By resetting the mooring barge to accord with the desired relation, or overlap, of successive sheets, a continuous interposition would be effected between the river and the caving bank under treatment. The slabs were to be reinforced with but strand and mesh such that maximum flexibility would be assured. Upon encountering check to their momentum in settlement toward final position, they would crack into wedge-shaped areas and fold over whatever inequalities were involved. Their several parts, however, would be held in juxtaposition by the embedded strand and mesh, ample virtue being thus retained for compliance with revetment requirements. Subsequent undercutting or erosion would be closely followed, due to the deficiency of cantilever value, resulting from the relation of area to thickness, such deficiency to be additionally regulated, if need be, by the creation of planes of weakness of any desired position and number. Satisfactorily long life would be assured by the galvanization to any desired degree of all or part of the reinforcement. The principal strand of the latter would be extended upon the upper bank slope and securely anchored in its pavement. Such a revetment would thus be essentially monolithic from top bank to deepest water. To provide for maximum plant capacity, an accelerator would be sought to hasten the hardening of the slab sufficiently to withstand launching, final hardening to continue, of course, upon the bed or bank revetted.

6. Experimental plant was designed to handle, in the fashion described, sheets 125 feet by 50 feet by 4 inches; slightly lesser sizes have been employed as a matter of precaution and of convenience.

7. The mat barges are of such shape and buoyancy that under the load of a slab and with some 180,000 pounds of water in a ballast compartment at the toe, the upstream edge of the mat is about 12 inches above the water surface upon beginning barge withdrawal, becoming submerged within a few feet of the movement. The several suspension lines, accordingly, come into action only after weight has been reduced to the extent of water buoyancy.

8. The inclined decks are subdivided sectionally by ways on 8 feet 4 inches centers, between which, platforms are so mounted on supporting timbers as to be readily lowered or raised by about 4 inches. In the raised position, these platforms are flush with butter or launching boards, which themselves rest upon rollers inserted in the ways. After slab manufacture and upon sufficient air hardening, the intermediate sections are dropped, the concrete structure thus

resting entirely upon the butter boards referred to. To launch a mat, it is accordingly necessary only to overcome the axle friction of the rollers, butter boards moving with the slab and being recoverable under proper provision for that purpose. The ways are steel shod to receive the wheel bearings of overhead trusses.

9. Mechanical equipment, mounted upon a standard wood mooring barge, consists of 35-horsepower upright boiler and double 7 by 7 inch engine equipped with drums, winches, etc.; of five intermediate trusses from which to suspend the slab, and of two end trusses carrying sheaves and lines whereby to effect mat barge manipulation. All trusses are hinged near the downstream edge of mooring barge and have wheel bearings for support upon the ways of the mat barge. These trusses may be raised or lowered in unison through rigging to engine on the mooring barge, which, as well, provides power through suitable lines for the maneuver and control of the barge to be withdrawn. The suspension trusses are of 5-panel point, Pratt type, spaced on 25-foot centers, the interval being subdivided by side stirrups from each main truss. All trusses are cross braced and interconnected by rods and shapes. Suspension is assumed from each panel point of both main trusses and stirrups and is, accordingly, on squares 8 feet 4 inches by 10 feet. Five supporting lines across the mat are thus available, each involving 15 suspension points. The supporting lines consist of three-eighths-inch cable, and wedged on outside trusses, passing thence through two fixed and one movable sheave above each suspension point to drums of a shaft located on the center truss. Lines from one side are wound over and those from the opposite side under the said drums. Prior to launching their lengths are fixed for support of the mat at desired submergence and the end brake of shaft thereupon set. As the mat relatively lowers during the withdrawal of barge upon which formed, these suspension lines come successively into play, and the total weight to be supported is accurately and automatically distributed to the several suspension points, due to the character of the operation and the fact that each suspension involves a movable sheave riding on a running line from center shaft to end trusses. No suspension, therefore, can take more nor less than its due proportion. Under the arrangement described, the weight of a slab of 100 tons in air is so subdivided that the main trusses take each but slightly over 11½ tons, the suspension points somewhat less than eight-tenths of a ton, and the supporting lines but about 900 pounds. As stated above, conditions are such that this advantageous subdivision of large weight is both accurate and automatic.

10. As a precaution against any uncertainty, or mishap, involving the safety of the main plant, the strength of mat loops, and of supporting lines, is materially less than any element of the carrying structures. If, therefore, a trigger should fail to trip, or other untoward incident eventuate, the mat loop involved should part or pull, or the suspension line break, before more serious result could develop.

11. The device employed at suspension points consists of a trigger attached to the housing of a movable sheave, and carries a pin, held by a spring in what may be termed a "locked" position. In "hooking up" a mat for launching, this pin is withdrawn by hand sufficiently to pass mat loop between pin and jaw. The trip device remains in the locked position while the mat is held in suspension. Connected to the tops of the several lock pins, are chains rigidly attached to the overhead trusses and of such length as to retain slack when the running suspension cables have taken weight, all chains to trigger pins being adjusted for as nearly the same amount of slack as practicable. To trip or release the mat from suspension, it is, therefore, necessary only to release brake

at the end of the shaft on center truss, whereupon the weight of the mat itself overhauls all suspending cables, thus taking up the slack of all trip chains, whereupon trigger pins are pulled practically simultaneously, and the mat released from any connection to the overhead structures. Many other methods are devisable to effect the same purpose.

12. To prevent the slab, during barge withdrawal, from tending to race off the latter, back-hold lines from shackle attachments at its downstream edge, to connections with overhead trusses, near their wheel bearings, are provided.

13. To withhold mat from movement with the barge during withdrawal, similar connections are made from its upstream edge to trolleys designed to travel vertically upon spuds of the mooring barge. The mat upon being tripped will, therefore, continue under control of its attachments to these spud trolleys, connection being severed at any predetermined depth by the withdrawal of shackle pins.

14. Upon release from suspension the slab can be controlled likewise by upstream and shore lines of appropriate number and anchorage.

15. Of the allotment available, $17,379.41 was consumed in constructing and assembling the plant described, and $4,019.97 was expended for all other items, of whatever character, involved in manufacturing eight and launching six slabs. A balance of about $3,600 is, therefore, on hand, represented by stock and cash.

16. The several slabs were reinforced by one-half inch strand around the edges, and on the lines of suspension and normal thereto, by five-sixteenth inch strand running diagonally through suspension points, and by triangular mesh over the whole area. Both strand and mesh were variously clipped and wired together. Suspension loops were made of one-half inch round iron in the form of hooks of uniform height and were engaged about the runs of strand at their several intersections.

17. The first mat handled was 50 feet by 50 feet by 3 inches, weighing 62,500 pounds; the second was 122 feet by 47 feet by 3 inches, and weighed 215,000 pounds; the last six have been each 122 feet by 42 feet by 3 inches, weighing 192,000 pounds. Width was cut from 50 to 47 feet in order to provide a somewhat longer bridle from spud trolleys to upstream edge of mat. It was again cut to 42 feet in order to reduce overhang above the first line of suspension which theretofore had caused objectionable drooping of this upstream portion of the slab.

18. Difficulty was experienced in starting slab No. 2, due, as developed by investigation, to insufficient lubrication of the mat barge ways, and to leakage between its sectional platforms of too fluid cement. All other mats, however, with proper lubrication, were launched readily under the application of an insignificant amount of power.

19. The transfer of all slabs from the mat barge to suspension was accomplished without incident involving difficulty or trouble of any character. The general scheme, in this regard, would appear to be unexceptionable.

20. With mats Nos. 2 and 3, the tripping was somewhat ragged, due, evidently, to their inclination to the horizontal in the position of suspension. In this respect, it developed that if a mat is released with material inclination, either up or down stream, it will tend to move, or skid, rather too rapidly in the direction of its inclination. This fact led to the suspension of the last three mats in a slightly humped shape, provided for by fixing the midsuspension lines at shorter length than those on either side. The up and down stream edges of these last three mats have thus been about 14 to 16 inches below midsection at the time of release.

21. The first five mats, upon being tripped, were controlled to position by the retention of their connections to spud trolleys for various depths up to 20 feet.

In each case, however, it was found that, due to the surge of the mooring barge upon release of the considerable weight involved, one or more spuds became bent. This result was apparently somewhat due, as well, to the rather short coupling from mat to spud trolley. The last mat handled was restrained after tripping, by shore and upstream cables.

22. The several mats were launched over a shelving bank, in from about 8 to 50 feet of water. Mat No. 1 was launched upon the upper part of the slope in about 8 to 12 feet. All others overreached a sharp break in the bank, their inshore edges being in depths of 6 to 18 feet, and their outer edges in depths of from 20 to 50 feet. All mats arrived at the bottom within reasonable limits of error, as indicated by corner buoys, that farthest out of desired position being mat No. 3 which moved downstream about 4 feet, and outshore about 8 feet. Mat No. 6, as to which the use of spuds was eliminated, and upstream and shore cables employed, settled within 12 inches of desired position. Its inner edge rested in about 18 feet and its outer edge in about 35 feet of water.

23. Three slabs launched during a high river, have been partly inspectable at lower stages. They are, to all intents and purposes, intact, being cracked only to the extent necessary for accommodation to bank inequalities, which are closely and satisfactorily followed.

24. This experimental work has extended over a period of some four months. Including all charges of whatsoever character, in any manner involved, the average cost, per square yard, of the several mats handled, has been 96.5 cents. Eliminating charges bearing no especial relation to the actual construction and launching of these slabs, but retaining those in any way intimately concerned, the average cost per square yard has been about 73 cents.

25. These figures include sand at $1 and gravel at $1.25 per cubic yard for the last four mats launched. In practice satisfactory river run can be dredged for about 20 cents. The usual inefficiency and correspondingly high cost of labor engaged upon unfamiliar experimental work, is, of course, likewise involved. Again, there has been used an obviously unnecessary amount of reinforcement and cement, which, however, have been employed as a matter of precaution. The slabs have been mixed, one of cement to from five to six aggregate; a one to eight mix is thought to be ample for all required purposes. It is further thought that the five-sixteenths inch diagonal and the edge reinforcement of one-half inch strand can be eliminated and that mesh of smaller section can be utilized.

26. Considering the matter upon the basis of reasonable reductions and eliminations, and assuming that a handling plant will provide for launching five slabs per day, a fair estimate of the field cost of going work does not exceed 48 cents per square yard. Realizing, however, the uncertainties which customarily attach to this class of speculation, and recognizing the desirability of keeping on the long side of the question, it is believed, that for further developments, a field cost of 60 cents per square yard should be assumed, which figure, it is confidently thought will prove to be conservative. The normal field cost of standard willow fascine construction, under this office, has been from 70 cents to 80 cents per square yard. It would not appear to be within the field of probability that concrete construction could exceed the lesser figure.

27. It is presumed that any form of revetment for the lower Mississippi River, should extend, at least, 250 feet from the bank.

28. If it be accepted that sheets of reinforced concrete are applicable in the manner developed by the experiments in discussion, the question arises whether a full width of mat can be handled in a single sheet, or whether a double run of " shingles " will be required.

29. Bearing in mind that no serious difficulty has attended the transfer from barge to suspension of a mat of 122 feet in length by 47 feet in width, weighing 215,000 pounds, and considering the fact that additional out-river dimension merely involves supporting units to scale, all within the limits of practicable construction and maneuver, no reason suggests itself why slabs of the extreme dimension can not be handled about as readily as those herein described. A greater slab area would simply be provided for by larger floating plant and additional trusses, each taking no more nor less than its due proportion incident to the manner of launching and the character of suspension employed. Moreover, with relation to the weight involved, attention is invited to the fact that, in the absence of any possibility of drift rack or ice jam, a 2-inch slab, heavily reinforced, ought to be about as effective for revetment purposes as one of any greater thickness. This consideration, however, is not necessarily important at this time, since, if the fundamental scheme is concluded to be appropriate, no physical nor mechanical reason militates against the adoption of any desired slab thickness within the limits of reason.

30. With a plant of assured stability the actual time required for launching a slab would necessarily be very small. "Hooking up" would be accomplished with a minimum of personnel and time, since the length of all suspension lines would be standard and the few mooring and restraining cables involved would be mainly under steam capstan control. Assuming a slab "hooked up" under the handling plant, the subsequent operation could not possibly consume 10 minutes. It therefore seems amply conservative to suggest that under reasonably resourceful management one handling plant should dispose of a slab in two hours or less. If five slabs per day, each 50 feet in width and placed with overlap of 10 feet, could be manufactured and launched, the net result of what may be termed channel mat construction would be 4,000 linear feet per month of 20 working days. Such a plant would be costly, but not disproportionately so in consideration of its output.

31. Reference was made heretofore to the fact that an accelerator for the hardening of concrete would be sought in the interest of increased plant capacity. To this end the Bureau of Standards was requested to investigate the subject and to advise whether an inexpensive element was discoverable of the properties desired. As a result the bureau reported that the addition to mixing water of from 3 to 4 per cent by volume of a saturated solution of calcium chloride would accelerate concrete hardening to the extent of apparently giving "results in 48 hours equivalent to 75 to 100 per cent of what we normally get in a month. We have tried this material out with a number of different cements and in different mixtures, and it has given very satisfactory results." The element named has been employed in the manufacture of six slabs with results consistent with the bureau's findings, from which it is concluded that concrete revetment mats can be launched during "normal concrete weather" within 48 hours of their manufacture. The advantages respecting plant capacity are, of course, obvious. With respect to the degree of hardness required for launching it should be observed that the concrete has no especial beam function to perform. It rests somewhat as an inert load in a hammock of metal, and thus requires hardness sufficient but to hold it together against general disruption after having attained its first set.

32. The progress of a single party on channel-willow mat construction will not average in excess of 50 feet per day. The plant involved comprises an average of 22 barges and 2 quarter boats whose fair value, upon the basis of half steel and half wood, is about $190,000. A comparable capital investment for the character of concrete operation herein suggested, estimated to do

equivalent work, namely, one handling barge and three mat barges in steel, five material barges and quarter boat in wood, mixing machinery, etc., would appear to total about $260,000. This contemplates the use of single sheets 250 feet by 50 feet by 3 inches or 4 inches.

33. The importance of developing an additional and, if possible, a better type of revetment than the willow fascine now employed has appealed broadly to everyone concerned. In addition to some evidences of the instability of fascine construction, an estimate of the cordage of suitable willows available, or likely to be available, points to their certain exhaustion in but a few years under any very largely increased revetment demands. The, perhaps, most evident substitute, namely, sawed lumber, is believed to hold too little promise of durability in the upper reaches of the river and to involve too serious handling difficulties to invoke serious consideration, to say nothing of other important objections. If concrete in the form of sheets or properly disposed blocks can be placed in assured position and with appropriate relation the most effective and durable of possible revetments would result. The plant and general proposition herein outlined will be observed to be fully applicable to the use of blocks handled in the same manner as a continuous sheet, though the latter is manifestly the more economical and effective form of construction if sufficient plant capacity can be provided for in the use of an accelerator, which is believed to be an established fact. Again, it will be noted, that for purposes of final flexibility a continuous sheet can be converted into the best possible type of "block" revetment by inexpensively running a cutter over the structure where desired while the cement is still sufficiently plastic.

34. The desirability of a more durable revetment, the importance, in any event, of supplementing willow construction, and the impending demand for a largely increased amount of the work, all point inevitably to the necessity of developing fully the merits of concrete, which can be done with finality only upon the commitment of substantial funds. The amount required in this regard, however, is relatively very small when considered against the cost and magnitude of the problem to which related.

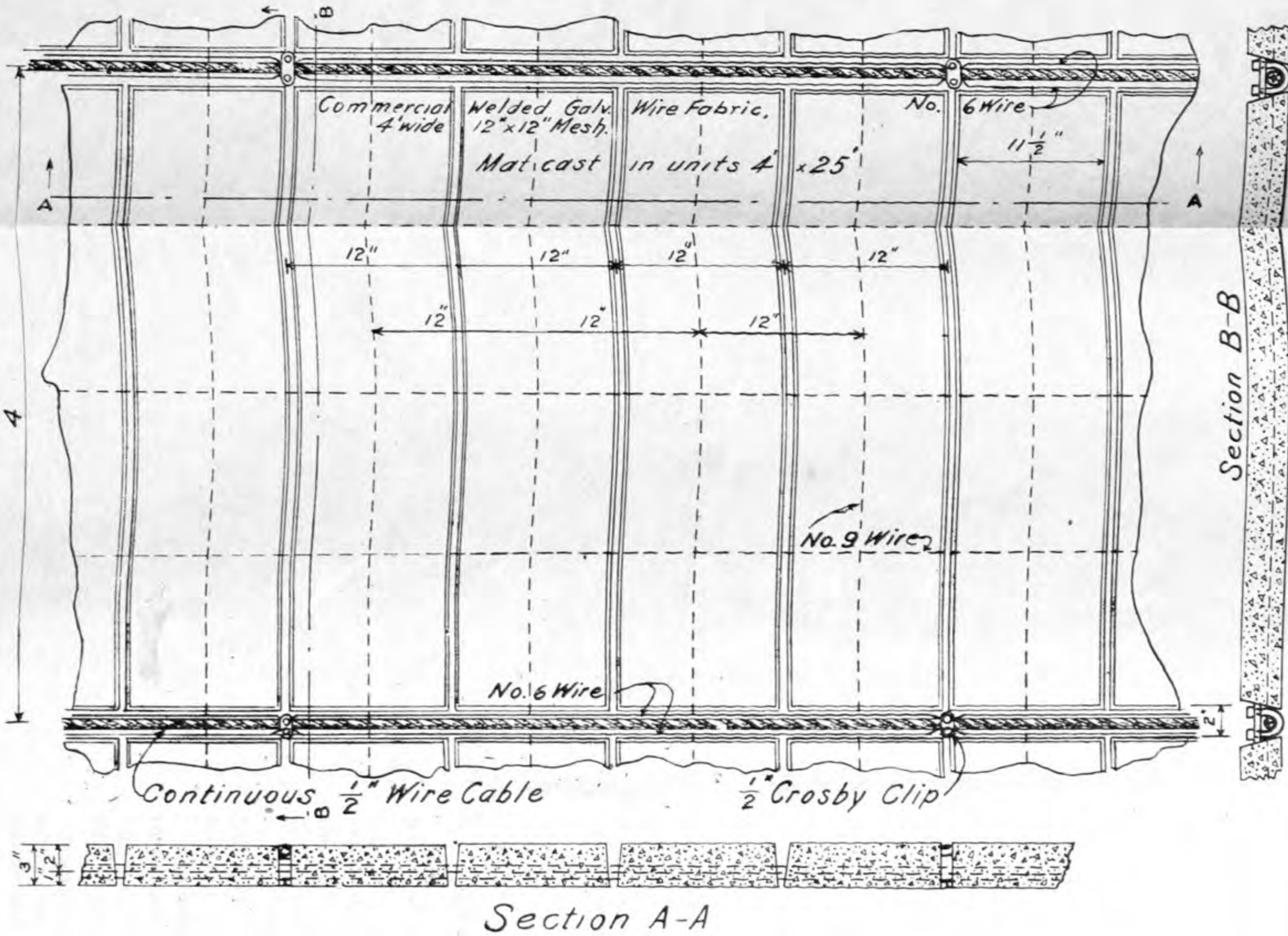
From funds made available by the river and harbor act of July 27, 1916, the commission allotted the sum of $150,000 for the construction of one complete unit of the type recommended by Major Markham for placing subaqueous concrete revetment, with a view of substituting this type of shore protection for the standard willow fascine type. The work of construction of this plant is now completed, and the plant will be given a try out during the working season of 1922. No try out was given in 1921.

An allotment of $8,000 for experimental revetment work in the third Mississippi River Commission district was made by the commission April 18, 1915.

The following report on reinforced concrete mats as manufactured and used for the revetment of caving banks in the third Mississippi River Commission district (391–609) was submitted by Assistant Engineer A. M. Todd in January, 1922:

Description.—Mats are formed of reinforced concrete slabs 3 inches thick, 11½ inches wide, and 3 feet 11 inches long, reinforced and connected with electric-welded wire reinforcement, 12 by 12 inch mesh; interior wires No. 9 U. S.

PLATE 13.



REINFORCED CONCRETE MAT
MATS PRECAST, 4' × 25'
Details of Reinforcement &
Method of fastening units together

MISSISSIPPI RIVER COMMISSION
THIRD DISTRICT, VICKSBURG, MISS.

Recommended by H. W. Todd. Asst. Engineer
Approved by J. C. O'Connor Major, Corps of Engrs.

To accompany report on
Reinforced Concrete Mat, dated
January 27, 1922

Traced by. H. d'A.

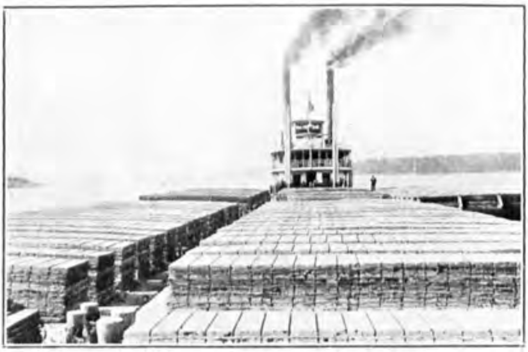
PLATE NO. 14.

LAUNCHING MATTRESS SLAB, SHORE END OF MAT BARGE.

LAUNCHING MATTRESS SLAB; SLAB SUPPORTED BY INTERMEDIATE TRUSSES, MAT BARGE MANIPULATION EFFECTED BY MEANS OF SHEAVES AND LINES CARRIED BY END TRUSSES.

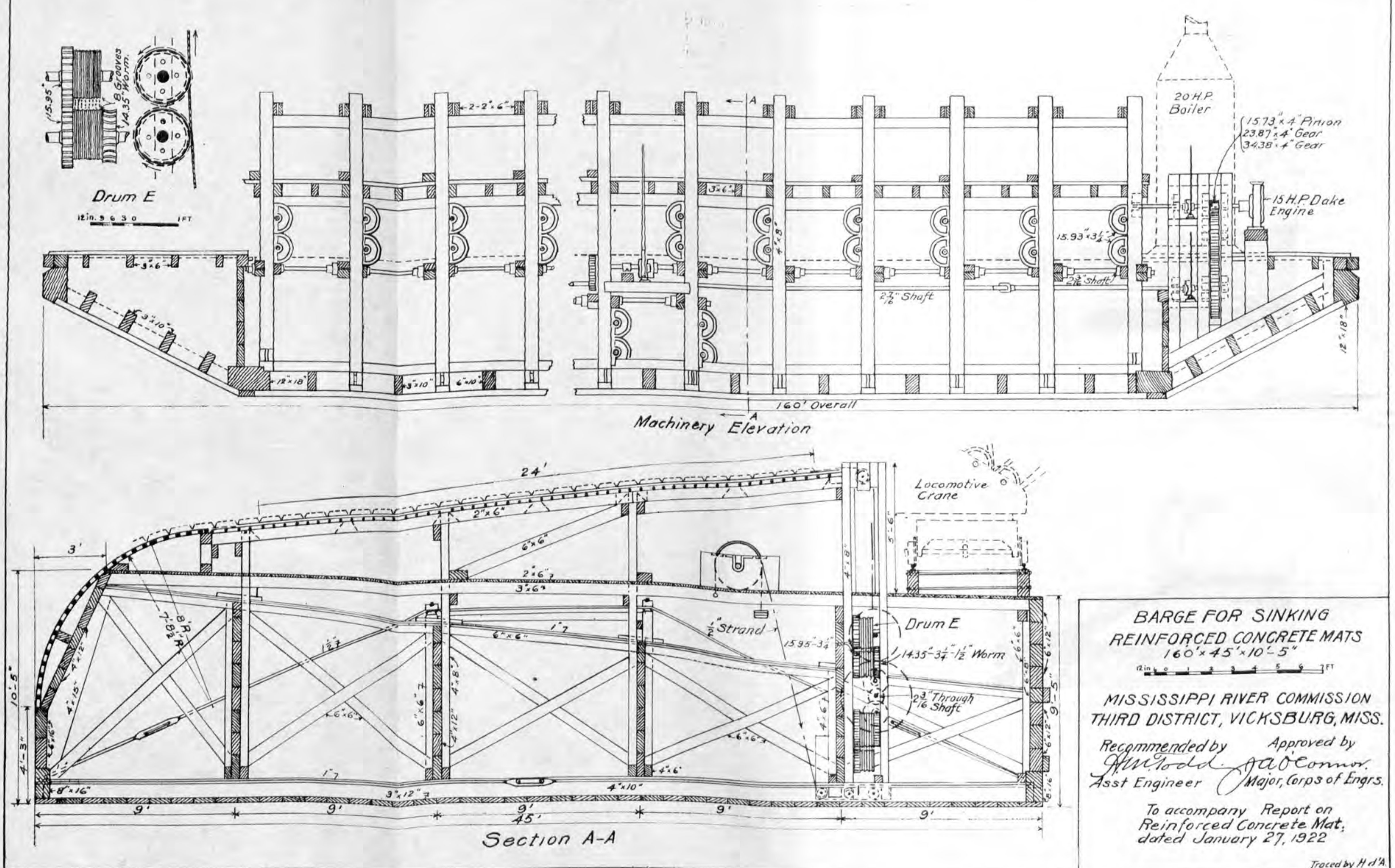
PLATE NO. 14—CONTINUED.

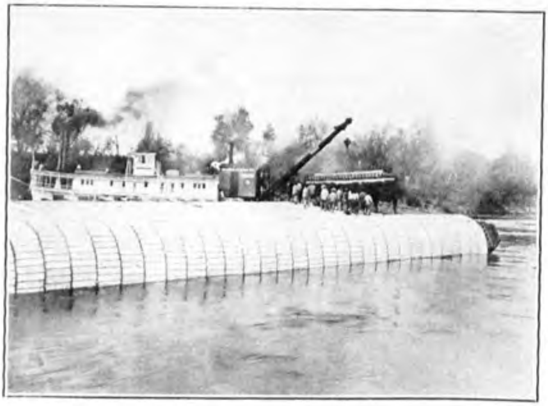
FLOATING CONCRETE MIXER POURING SLABS FOR "UNIT TYPE" CONCRETE MATTRESS OF THIRD MISSISSIPPI RIVER DISTRICT. UNIT IS 4 BY 25 FEET. AND IS COMPOSED OF 25 SLABS.



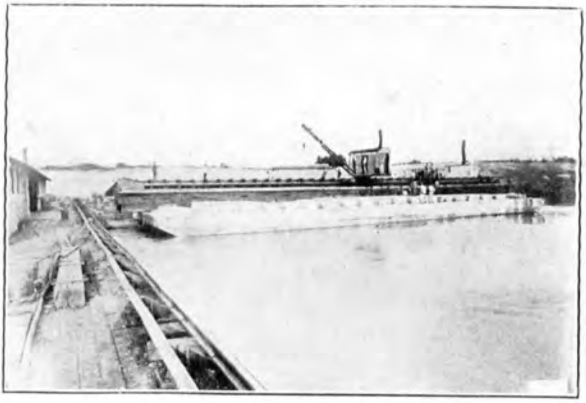
UNITS IN TRANSIT FROM MIXING PLANT AT GRAVEL BAR TO MAT SINKING PLANT.

PLATE 15.


Drum E
8 Grooves
14.35" Worm.
15.95"
20 H.P. Boiler
15.73" x 4" Pinion
23.87" x 4" Gear
34.38" x 4" Gear
15 H.P. Dake Engine
2 3/16" Shaft
160' Overall
Machinery Elevation
24'
3'
Locomotive Crane
1/2" Strand
Drum E
14.35"-3 3/4"-1 1/2" Worm
2 3/16" Through Shaft
10'-5"
9'-5"
45'
Section A-A
BARGE FOR SINKING
REINFORCED CONCRETE MATS
160' x 45' x 10'-5"
MISSISSIPPI RIVER COMMISSION
THIRD DISTRICT, VICKSBURG, MISS.
Recommended by
Asst Engineer
Approved by
Major, Corps of Engrs.
To accompany Report on
Reinforced Concrete Mat,
dated January 27, 1922
Traced by H d'A.

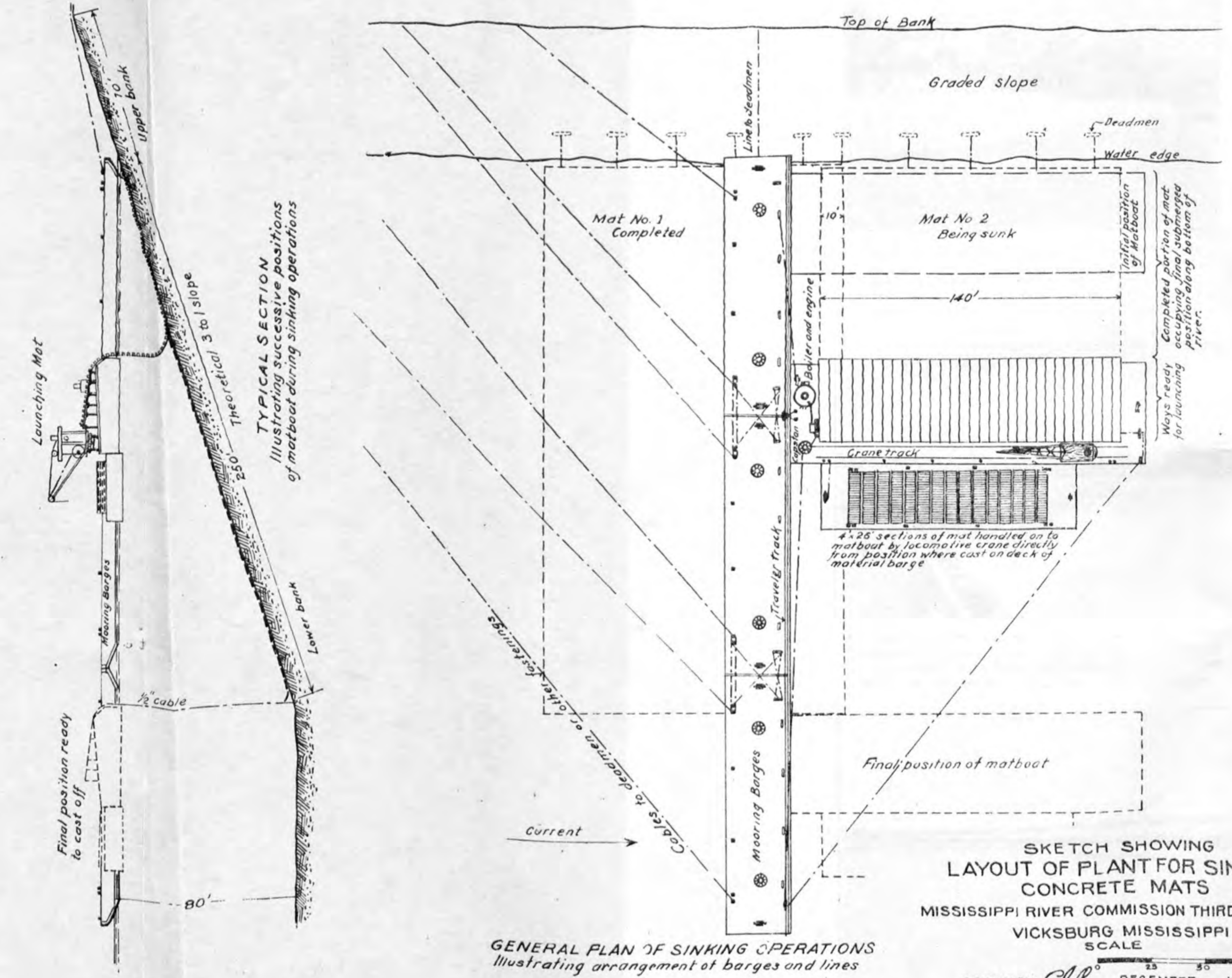


AFTER THE MAT SECTION HAS BEEN LAUNCHED, A NEW TIER OF UNITS IS LAID (ON THE WAYS) AND FASTENED TO THE ½-INCH CABLES AND TO THE ENDS OF THE UNITS PREVIOUSLY LAUNCHED, THUS FORMING A UNIFORM MAT.



A LOCOMOTIVE CRANE, TRAVELING THE FULL LENGTH OF THE LAUNCHING BARGE, TRANSFERS THE UNITS FROM THE MATERIAL BARGE TO THE WAYS BY MEANS OF A SPECIAL LIFTING FRAME.

BANK PAVEMENT FORMED BY LAYING MAT UNITS ON THE UPPER BANK.



SKETCH SHOWING
LAYOUT OF PLANT FOR SINKING
CONCRETE MATS
MISSISSIPPI RIVER COMMISSION THIRD DISTRICT
VICKSBURG MISSISSIPPI
SCALE
0 25 50 75 100

DRAWN BY C.J.R. DECEMBER 1919

Traced by H.d'A.

101/17

102067—22. (Face p. 43.)

Standard, and exterior longitudinal wires No. 6 U. S. Standard. Reinforcement is exactly 48 inches wide outside wire to outside wire, and is cut in strips 25 feet long, thus forming 25 slabs in each mat unit, each of which is 4 feet by 25 feet (100 square feet), weighing about 2,500 pounds. (See cut "Mat connection" on Plate No. 13; also photograph, Plate No. 14.)

Manufacture of mat units.—The equipment required consists of 1 quarter boat, 1 gravel and sand dredge, 2 or more gravel barges, 1 floating concrete-mixing plant, and from 6 to 24 standard material barges. (See photograph, Plate No. 14.)

Six or more barges are moored end to end in a suitable location as near as possible to a good gravel bar; the floating concrete mixer travels up and down the line of barges; the barge containing sand and gravel is moored on the outside of the mixing barge; a mix of 1:2:3 is used with a run of bar aggregate dredged hydraulically, the output carefully screened so as to give the above proportions. The quick curing of the mats is necessary, because the barges are idle during the curing period, and should be unloaded as quickly as possible, so that a minimum number of barges will be required for continuous operation by both the casting and the sinking plants.

Forms well coated with black oil are laid out on the material barges, accurately forming the mat units as described, and the wire fabric is held in place by a special clip. (See photograph, Plate No. 14.) Enough barges and forms are laid out to make up a day's run for the mixing plant; the concrete is poured into the forms from the bottom of the bucket traveling in and out, the mixing boat shifting downstream between forms and from barge to barge.

The forms are pulled after the concrete is sufficiently set, which is usually in about three hours after pouring; a strip of heavy "Craft" paper, 50 inches wide, is laid over the green concrete unit, and forms are relaid on top of the paper ready for the next run. The runs can usually be made 24 hours apart, and during the long summer and fall days two runs can be made in one day. About 150 squares is an average day's run. When each barge is loaded it contains 19 full piles of 12 units each, and one pile at each end of the barge with six units each, making a total of 240 units (or squares) on each loaded barge. (See photograph, Plate No. 14, showing a tow of 1,000 squares on four loaded barges.)

Description of mat-sinking boat.—(See blue print, Plate No. 15.) The mat-sinking plan consists of a scow-built barge 160 by 45 by 9½ feet on which is constructed launching ways 4 feet apart, forming a mat-building platform 28 by 140 feet. Along the ways a 2½-ton locomotive crane travels the full length of the barge. (See photograph, Plate No. 16.) At each skid, worm-driven friction drums are arranged to pay out the one-half-inch galvanized wire rope strand continuously. The worms are driven in groups, each controlling five sections, by suitably geared shafting, which is in turn driven by a main shaft running from end to end of the boat. The main shaft is driven by a 25 horse-power Dake steam engine. Each group of drums can be thrown in or out with clutches, so that the mat can be launched as a whole, 140 feet wide, or in sections of 20 feet wide each. Thus more or less mat can be paid out and inequalities in the river bottom being covered allowed for.

Placing or sinking mats.—Plant required, one quarter boat, one mat-sinking boat, three or more mooring barges, one line barge, one harbor tug, necessary mooring lines, tackle, etc. For standard Mississippi River mats averaging 250 feet from edge of low-water line to maximum depths, three mooring barges are required, moored into position as shown on blue print, plate No. 17. The mat boat is placed at initial position shown as close to the water's edge as

possible. A loaded barge of the mat units is moored on the outside of the mat barge away from the shore. The locomotive crane lifts the units with a special lifting frame. (See photograph, plate No. 16.) The units are laid in position on the platform, the two side wires of each unit are fastened to the one-half-inch wire rope at each skid with Crosby clips spaced about 4 feet apart. When 35 units are laid a section of mat 25 by 140 feet has been formed. This section is then paid off or launched by driving all the friction drums. The mat moves off freely on account of resting on the lines of rollers forming the top of each skid. After the mat section is launched a new tier of units is laid and fastened to the one-half-inch cables and to the ends of the units previously launched, thus forming a uniform mat. (See photograph, plate No. 16.) A second launch is then made which places the edge of the mat on the bottom. By the time the third launch is made the mat boat is shifted out on the mooring barges as the mat is launched, thus causing the mat to lay smoothly and evenly on the bottom of the river. Photograph, plate No. 16, shows rail upon which traveling bitts move, to which the mat-sinking boat is moored and which allows the boat to be readily shifted along the mooring barges. Mat sections are laid and launched in similar manner until the maximum depth is reached. The last launch is continued until the entire mat is resting on the bottom; the one-half-inch cables are then cut at the water's edge; the mooring barges are dropped downstream 130 feet to a new setting, and the operations are repeated as described for mat No. 1, leaving a lap of 10 feet over the mat previously sunk.

Connection with the upper bank paving.—The reinforced-concrete mats should be placed on bank previously graded and prepared and sinking operations begun at as high a stage as possible. The edge of the mat as sunk is usually about 5 feet below the surface of the water and after a fall of 5 feet or more the upper-bank paving is connected with the edge of the mat. If the mats are sunk at an extreme low stage, the connection is made after the water has risen some 5 to 10 feet by laying a strip of mat as wide as necessary, placing the mat boat normal to the bank line and sinking continues from upstream proceeding downstream. Connection mats have been safely placed in this manner where the velocity of current has not exceeded 1 foot per second in depths not more than 20 feet. This method of sinking the connections has not proven entirely satisfactory, and it is proposed to construct an auxiliary mat-sinking unit arranged so that the mat will be launched off the end of the barge with an overhanding rake so as to lay the edge above the water line. This barge will lay mats about 40 feet wide and as far out as necessary to connect with the main or channel mat, and will be designed to follow closely after the main mat is sunk and the upper-bank paving placed at once so as to make the operations of laying the revetment entirely independent of the fluctuations of the river to within bank full limits. Connections have also been made by building willow connecting mats ballasted and sunk with stone or concrete ballast.

Upper bank paving.—The mat units (4 by 25 feet) have been successfully used within the past two years for upper-bank paving; the units are lifted with a derrick, using the same frame for engaging the side wires as described for use in forming the subaqueous mats. The separate blocks have also been used for upper-bank pavement laid in the same manner as broken stone riprap. Photograph, plate No. 17, shows bank pavement formed by laying the units on the upper bank.

Development and extent of reinforced concrete mats placed.—The reinforced-concrete mats as described were developed in the third Mississippi River Commission district in 1915-16, under the instruction and supervision of the Mississippi River Commission.

The sinking operations have not been successful so far if the flow is at a much greater rate than 4 feet per second, due principally to the fact that the mooring barges and the track carrying the traveling bitts have not been sufficiently strong to stand the severe strains resulting from the high velocities. The track will be greatly strengthened and the mooring barges placed in condition to meet all conditions during the present lay-up season, and it is believed the mats can then be laid under the most severe current conditions.

Following is a summary of bank revetment constructed to date with reinforced-concrete mats:

Locality.	Year placed.	Linear feet bank revetted.	Number of squares (100 square feet) placed.	Field cost per square in place.
Vicksburg Harbor	1917	1,800	4,024	$7.64
	1918	2,500	3,910	9.10
Red Fork, Ark. (Arkansas River)	1917	1,800	5,680	6.67
	1918	2,200	7,574	6.90
Ashbrook Neck, Miss	1918	1,100	3,076	10.71
	1920	1,000	3,683	20.09
Princeton, Miss	1918	1,000	3,129	11.74
	1919	1,400	4,659	13.78
Pendleton, Ark. (Arkansas River)	1920	1,200	1,755	23.47
	1921	600	800	20.58
Opposite Delta Point	1919	800	2,064	24.22
Arkansas City, Ark	1920	2,000	8,827	23.30
Valewood, Miss	1921	2,800	9,356	12.50

All of the above revetment has been effective in checking the caving banks. Some failures at Princeton, Miss., were noted after the work of 1918, but these were due to the extremely sandy character of the bank, together with the fact that the upper bank and the subaqueous mats had not been properly connected. The work at Vicksburg Harbor, Red Fork, and Ashbrook Neck has been in place more than three years at this writing and no repairs to the subaqueous mattresses have been necessary. Photograph, plate No. 16, gives a view of about 1,000 feet of completed bank revetment at Valewood, Miss.

SPUR-DIKE REVETMENT.

Spur-dike revetment work consisted in building a series of spur dikes made of brush and pole cribs, ballasted with stone and sunk on a sill mattress for a foundation. Spur dikes of this description were used at New Orleans Harbor as early as 1884, and at Memphis Harbor (226) in 1886, and at Columbus, Ky. (21), and Helena, Ark. (306), in 1889–90.

At New Orleans Harbor (960–970).—Each spur dike rests on a wide mattress made of willows, brush, and timber, which is sunk in place by being loaded with stone, and which is intended to prevent any scouring action on the river bottom by eddies or local currents which may be produced by the dike. On this mattress the dike is built up by sinking successive layers of mattresses or cribs of diminishing widths, the construction of which is similar to that of the foot mattress, except that they are made thicker. The work is so planned that the top of the completed dike at the shore end will be below low-water line, and the crest of the dike has an approximately regular slope of about three horizontal to one vertical, its outer end resting on the river bottom in deep water. In the vicinity of wharves and docks the crest of the dike is placed

low enough so it will not interfere with vessels, but in other localities the crest has been continued up to and united with the crest of the levee or the bank by an earth embankment paved with stone.

These structures are designed to check the velocity of the current along the shore, and thus diminish the erosion and caving of the bank, and cause deposit of sediment and the restoration of the bank line.

In certain localities their direct effect in bracing up the bank, and so preventing the caving which is liable to take place during the falling of the river, is also believed to be beneficial, at least locally.

When this form of structure is used, where the existing slope of the submerged portion of the river bank is not steep, the foot mattress probably becomes the most important part of the spur, and the dikes act more as an interrupted bank revetment. (Report of Mississippi River Commission for 1892, p. 3218.)

The specifications for this work were as follows:

Method of constructing mattress.—The mattress will be constructed in position for sinking, and will be made of willow brush and poles, the brush to be woven on the poles, which will be 25 feet long and 8 feet apart, the longitudinal and transverse strength of the mattress to consist of iron rods, those which run parallel to the poles to be fastened to them, and to be in separate links of 25 feet, and joined with clevises; those which cross the poles to be made in a chain 350 feet long, with links of 8 feet, and to be connected with the clevises in the first system of rods; these chains to run through the mattress 25 feet apart, and to extend back on shore to logs sunk in the ground; the upstream, downstream, and deep-water edges of the mattress to be double in the thickness for a width of 8 feet, with a large quantity of rock between, which will be put in when the mattress is constructed. This will insure the ballasting of the edges of the mattress, and prevent their rising up and dumping the ballast. It is estimated that it will require 7.8 pounds of rock weighed in water to ballast a square foot of the mattress.

Method of constructing spur.—In order to expedite the work so that it can be completed in one season it will be necessary to build the cribs at some point above and float them down as they are needed for sinking. A few piles hauled out on shore will be sufficient ways for building the bottom of the crib. It can then be launched and finished on the water. It will be constructed of willow brush and poles, yellow-pine timber, and iron rods, leaving pockets into which the rock can be thrown for sinking it. The capacity of the pockets will be one-fourth of the size of the spur.

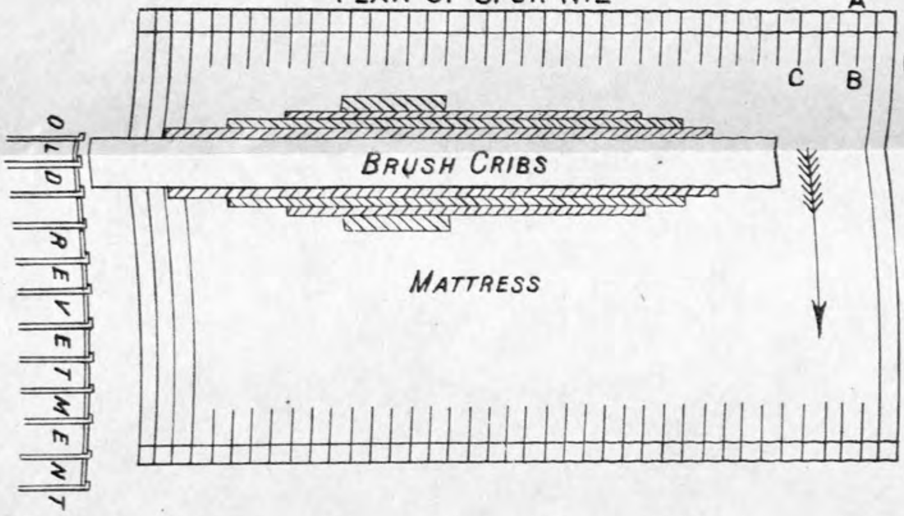
It will be so constructed that when the iron rods rust away it will still hold together, and it will be so made that it can bend to the curve of the bank. The details of construction may have to be changed during the course of the work.

Method of sinking spur.—For sinking the spur two lines of barges will be required, one on each side of the spur; rock to be thrown in the crib until the pockets are full, and it will then be lowered to the bottom by ropes from the barges. To prevent the barges overturning, it will be necessary to build two longitudinal water-tight bulkheads in each, and the water will be let in on one side of the barge as the ropes pull down on the other. It may be necessary also to use a small quantity of rock as a counterbalance. The weight of a complete spur will sink one side of two 30-foot barges 2.4 feet.

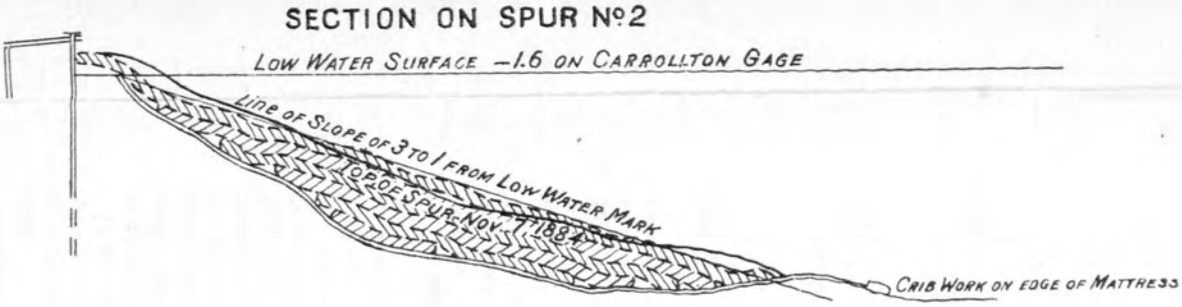
The buoyancy of a cubic foot of the spur will be about 7½ pounds, and to overcome this and insure the stability of the spur, it will be necessary to use

PLATE 18.

PLAN OF SPUR No. 2



SECTION ON SPUR No. 2



NEW ORLEANS HARBOR, LA.

DETAILS OF MATTRESS AND CRIB WORK

PLACED 1884 TO 1888

SCALE, 1:1000

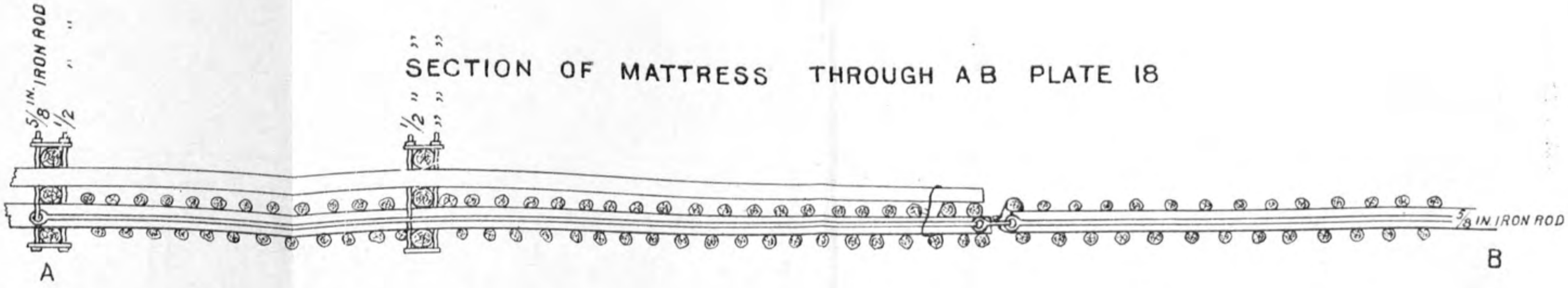
50 0 50 100 150 Ft.

Traced by H. d'A.

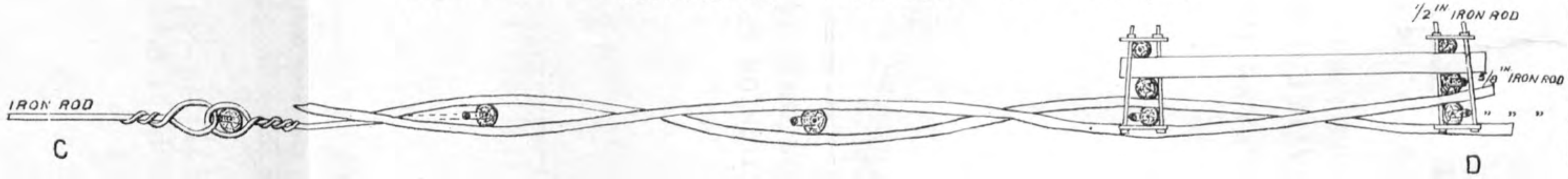
102067—22. (Face p. 47.)

PLATE 19.

SECTION OF MATTRESS THROUGH A B PLATE 18



SECTION OF MATTRESS THROUGH C D PLATE 18



NEW ORLEANS HARBOR, LA.

DETAILS OF MATTRESS AND CRIB WORK

PLACED 1884 TO 1888

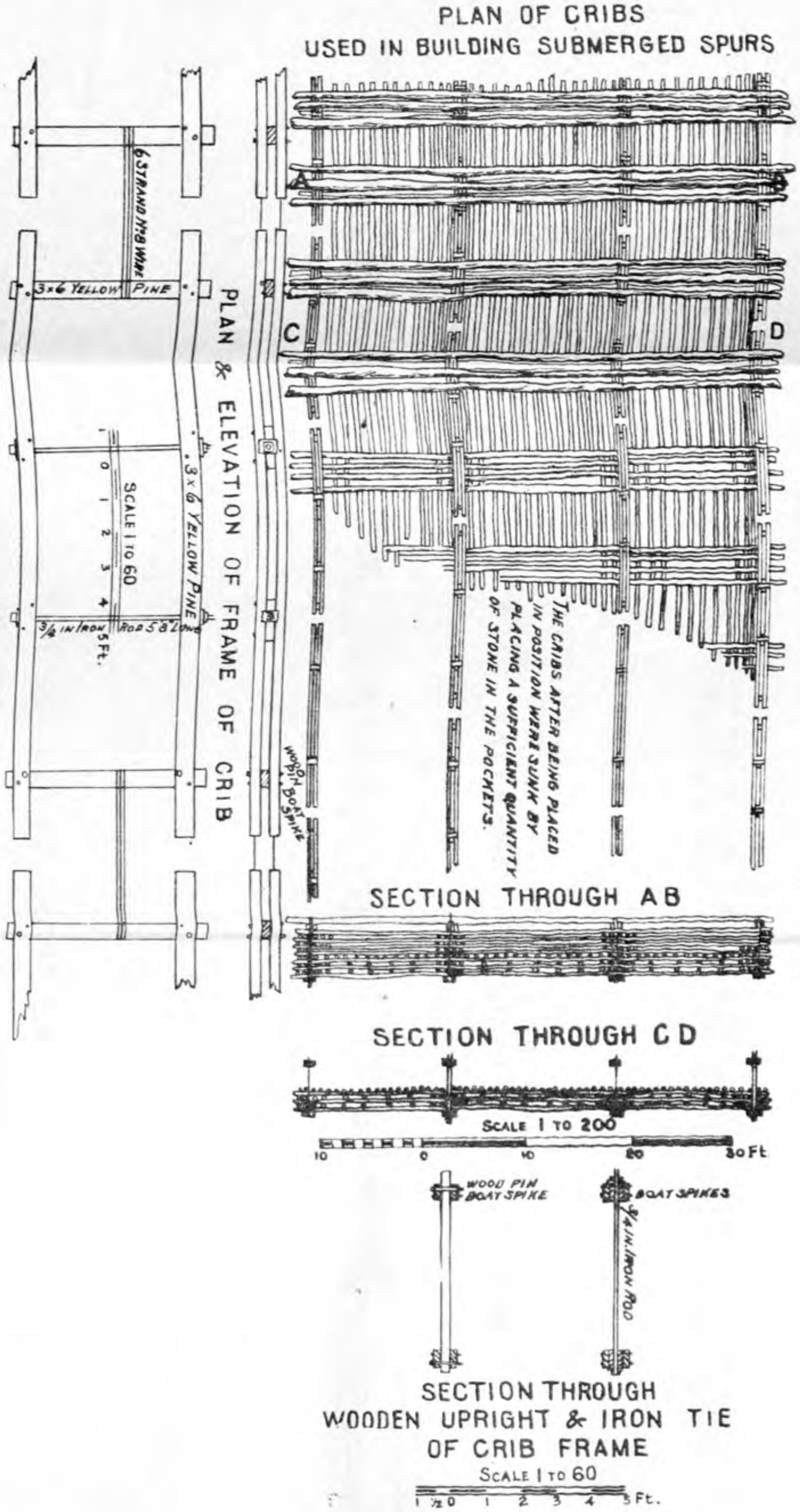
SCALE, 1 TO 100

5 0 5 10 15 20 Ft.

Traced by H.d'A.

102067—22. (Face p. 47.)

PLATE 20.



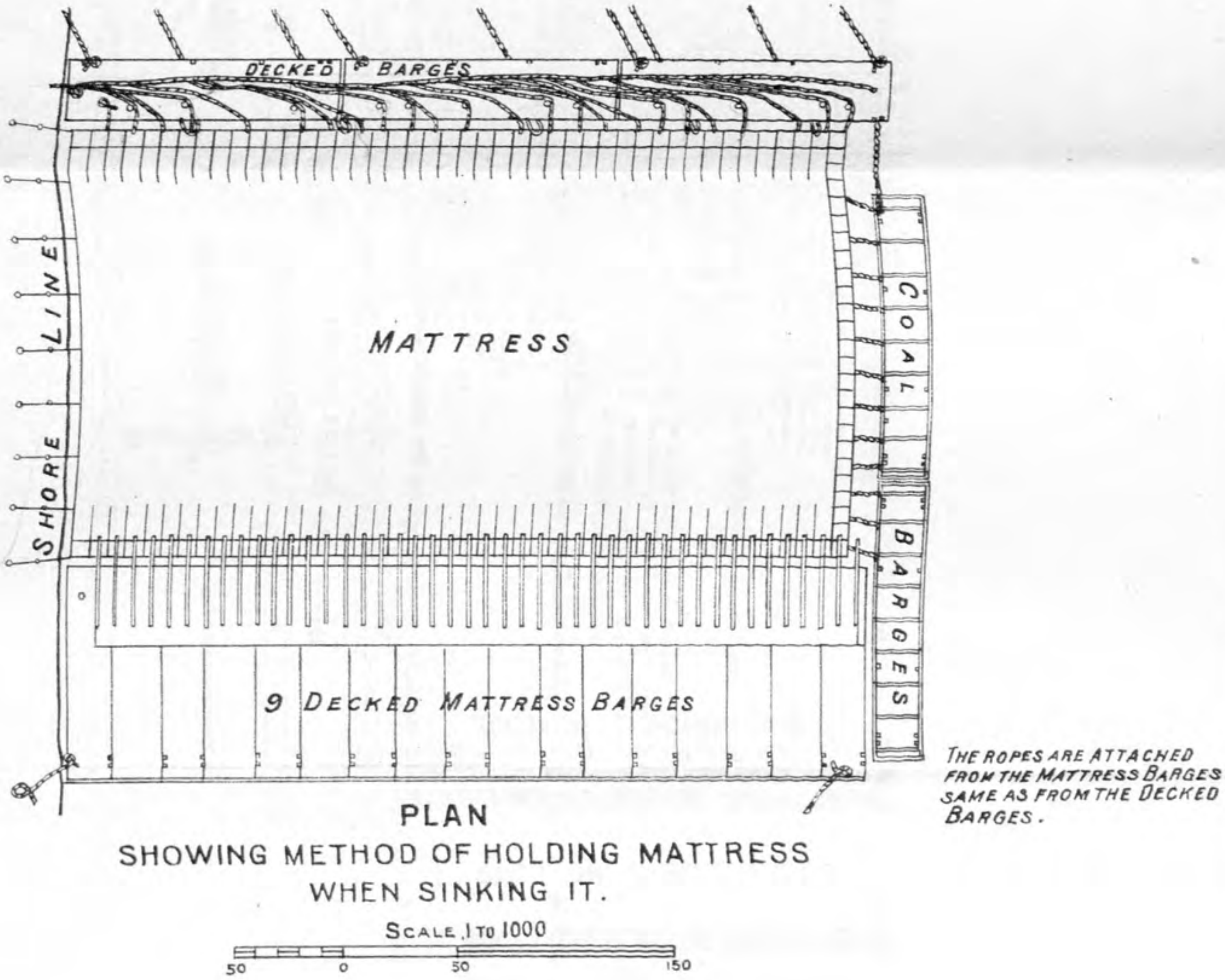
NEW ORLEANS HARBOR, LA.

DETAILS OF MATTRESS AND CRIB WORK
PLACED 1884 TO 1888

Traced by H. d'A.

102067—22. (Face p. 47.)

PLATE 21.



PLAN
SHOWING METHOD OF HOLDING MATTRESS
WHEN SINKING IT.

SCALE, 1 TO 1000

NEW ORLEANS HARBOR, LA.

DETAILS OF MATTRESS AND CRIB WORK
PLACED 1884 TO 1888

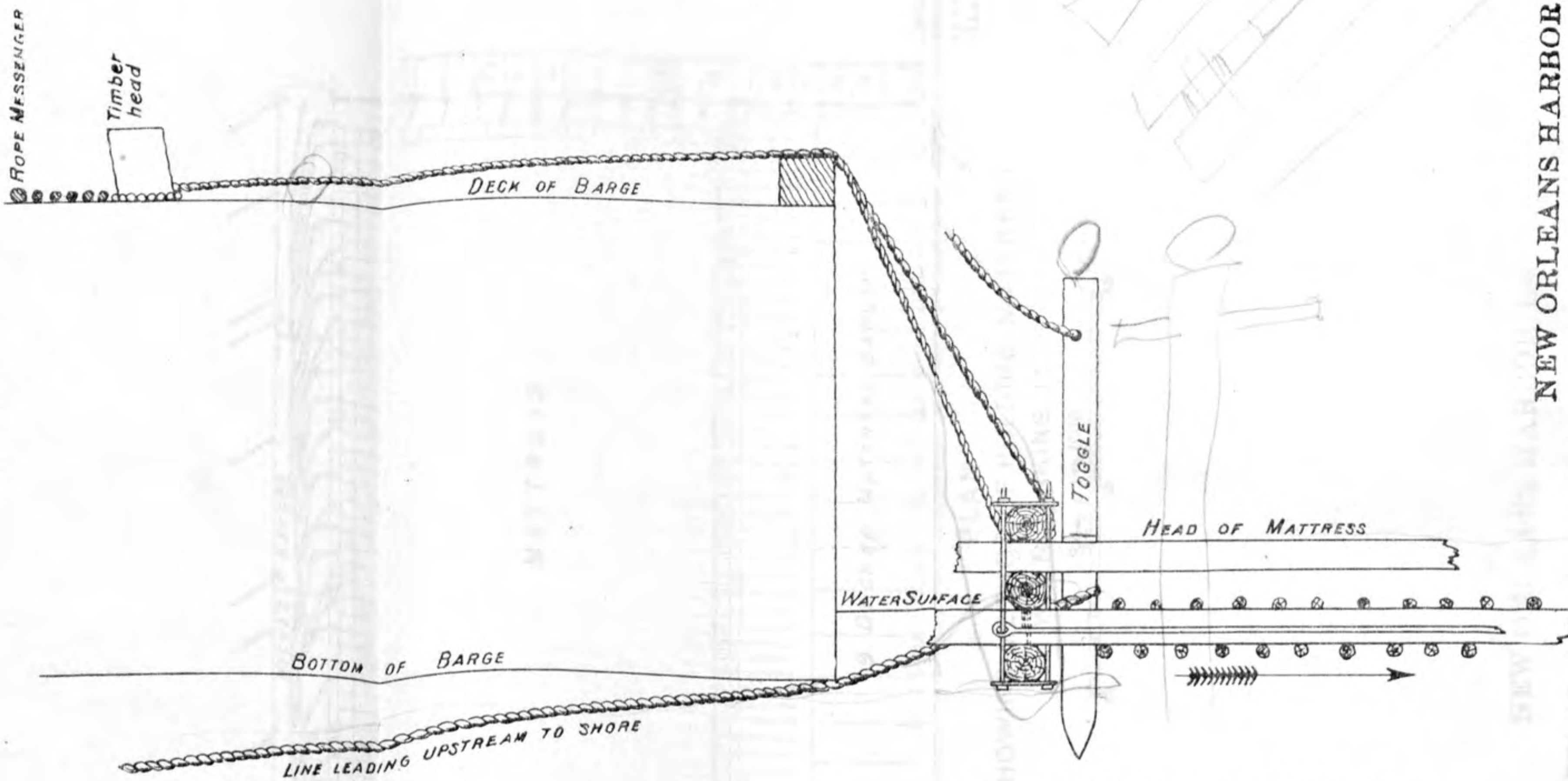
Traced by H.d'A.

PLATE 22.

NEW ORLEANS HARBOR, LA.

DETAILS OF MATTRESS AND CRIB WORK

PLACED 1884 TO 1888



SECTION SHOWING METHOD OF HITCHING LINES TO MATTRESS

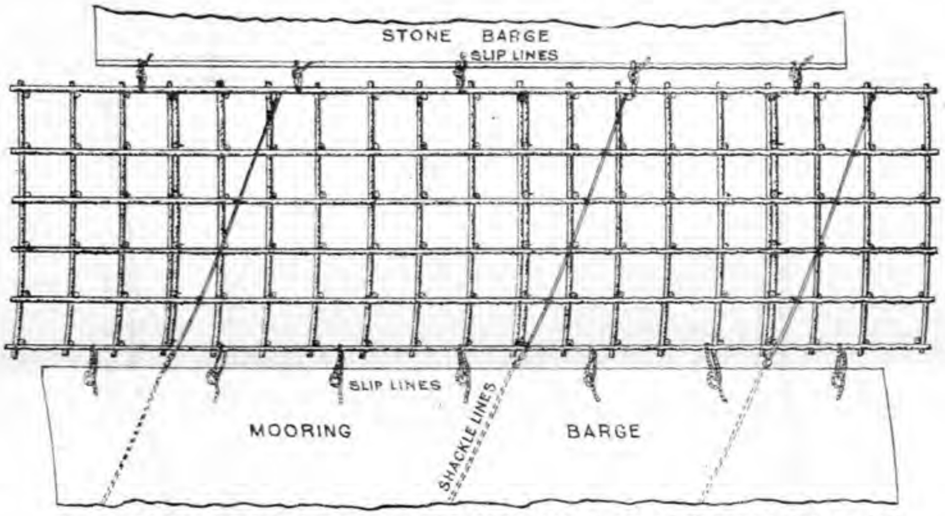
SCALE, 1 TO 30

1 0 1 2 3 4 5 6 7 8 9 Ft

Traced by H.d'A.

102067—22. (Face p. 47.)

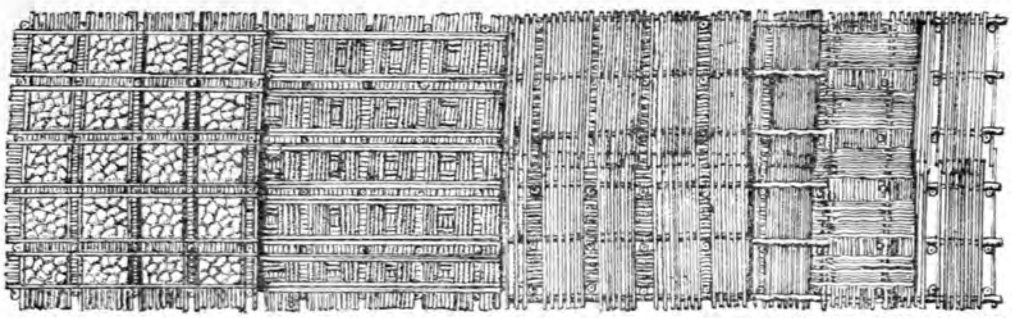
PLATE 23.



PLAN SHOWING METHOD OF FASTENING LINES TO CRIB WHEN SINKING IT.

SCALE
10 Ft. 0 10 20 30 40 50 Ft.

PLATE 24.



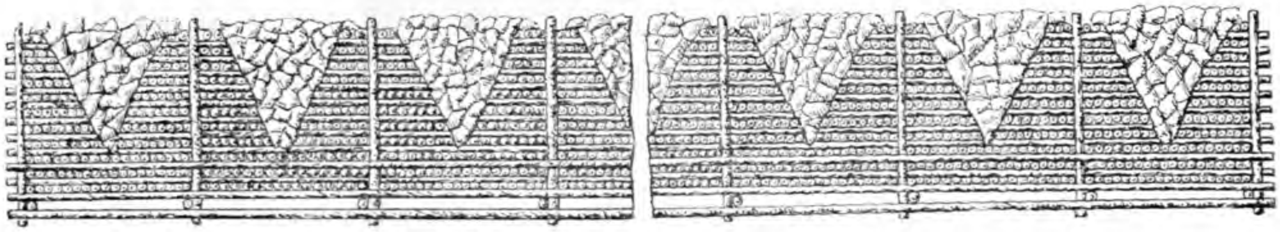
THIRD LAYER SECOND LAYER FIRST LAYER

CRIB WHEN BALLASTED CRIB WHEN FINISHED BOTTOM OF POCKET BOTTOM OF CRIB

PLAN OF CRIB

SCALE
10 Ft. 0 10 20 30 40 50 Ft.

PLATE 25.



LONGITUDINAL SECTION OF CRIB

SCALE
10 0 10 20 Ft.

MEMPHIS, TENN.

SPUR DIKE REVETMENT

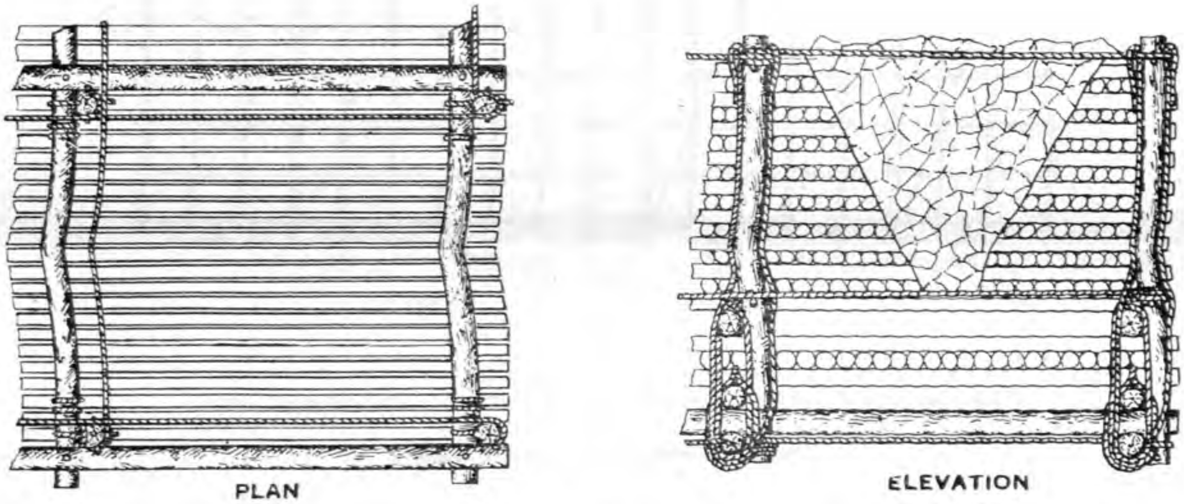
DESIGNED AND CONSTRUCTED BY

CAPT. SMITH S. LEACH

CORPS OF ENGRS. U.S. ARMY.

Traced by H.d'A.

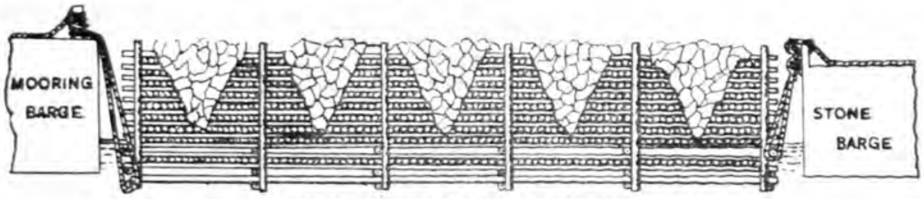
PLATE 26.



PLAN AND ELEVATION OF ONE SECTION OF CRIB
SHOWING METHOD OF WIRING

SCALE
5 0 5 10 Ft.

PLATE 27.



CROSS SECTION OF CRIB

SHOWING METHOD OF FASTENING LINES TO CRIB AND BARGES

SCALE
10 0 10 20 Ft.

MEMPHIS, TENN.

SPUR DIKE REVETMENT

DESIGNED AND CONSTRUCTED BY

CAPT. SMITH S. LEACH

CORPS OF ENGRS. U. S. ARMY.

Traced by H.d'A.

15 pounds of rock weighed in water to the cubic foot of spur, which will require the spur to be constructed three-quarters of brush and one-quarter of stone. To give it increased stability, iron rods will run from the spur diagonally upstream to the shore and be fastened to logs sunk in the ground.

Plant required.—The plant for the work should consist of six barges, each 30 by 124 by 7½ feet, decked, and containing two longitudinal water-tight bulkheads; three of the barges to have mattress ways constructed on them, so that they can be placed end to end and a mattress 350 feet wide built on them. To do the necessary towing a steam tug or stern-wheel steamboat will be required. The plant will be such that it can be used for any future mattress work in the harbor. (Annual Report, Mississippi River Commission, 1884, p. 312.)

In 1892 the methods of constructing and sinking the mattresses and cribs were the same as in 1884, except that the cribs were built and launched from floating ways instead of on ways on the bank. The float had just enough buoyancy to support the crib timbers and the first layer of willow brush. This method was found to be cheaper and better than the old one.

Details of spurs and cribs are shown on Plates Nos. 18–22.

Spur dikes at Memphis.—Each spur in the Citizens' Dikes at Memphis was founded on a sill mat, 200 feet wide at the high-water line on the bank and extending from the high-water line out into the river about 350 feet beyond the low-water line. The dikes consisted of cribs built in successive layers on the sill mats. The cribs had a maximum thickness of 8 feet, the width of the top crib was 16 feet, and the width of the other cribs below it increased in width successively by 16 feet. The details of the construction are shown on Plates Nos. 23–27.

Constructing cribs.—A grillage of poles was made, forming 8-foot squares, and upright posts from 8 to 10 feet high were placed at the corners of the squares. Eighteen inches of brush, in three alternating layers, were placed on the grillage, then a pole grillage was placed on the brush, which was compressed by wiring the two grillages together. Ties of wire strand or iron rods were run across the upper grillage and were secured to it, and straps were placed for attaching mooring lines. This bottom of the crib was built on floating ways, and was then launched. When the bottom was completed, double lines of poles were placed between the rows of posts, each line of poles being near the center of the squares in the grillage below, and the spaces between the lines of poles and post were filled with brush. Similar poles and brush fillings were placed at right angles to those last placed. This alternating construction was continued, the successive lines of poles being farther and farther apart until the poles were close to the post at the top of the crib, thus forming a hopper for holding stone over each 8-foot square of the bottom grillage. Each pole was nailed to all other poles it crossed, and the completed structure was compressed with levers and tied together with wire

strands which had been carried up along each post. Other wire strands were run from post to post both longitudinally and transversely over the top of the structure.

Spur dikes for breaking up eddies.—Spur dikes have been built at a number of localities in pockets in revetted banks, with the design of breaking up the violent eddy currents which generally exist in such pockets and which are detrimental to the stability of the revetment. In some places these pockets were entirely covered with a floor mattress and the dike built on this. In places where a large pocket has resulted from a recent failure of the revetment the dikes were founded on the usual sill mats only.

INSTRUCTIONS FOR REVETMENT WORK.

The following instructions for revetment work were adopted by the commission April 23, 1918:

1. It is hereby directed that in all work of bank revetment under the Mississippi River Commission the slope of the caving bank from the low-water shore line to a line 50 feet beyond the foot of the slope shall be covered with a continuous mattress of willows or concrete.

2. The bank above the low-water line shall be graded to a slope of one on three to one on four. This graded bank shall be paved with riprap stone closely laid by hand, making a substantial covering not less than 10 inches thick. Concrete 4 inches in thickness shall be used in lieu of stone wherever such use will result in equal or greater efficiency and economy.

3. Low stages of river are preferable for bank revetment work, but owing to the short duration of such stages it will often be necessary to continue operations at higher stages. Under these conditions the width of the mat shall be such as to cover the slope of the bank from the shore line out to a line 50 feet beyond the foot of the slope.

4. Where a rapid rise in the stage of the river prevents the upper bank paving from being connected with the subaqueous mattress, or where the width of the mat required exceeds the normal capacity of the plant, connecting mats of suitable size may be used.

5. The portion of the bank above the low-water line covered by willow mats will be graded and paved at such time as the stages of river and availability of plant will permit.

6. Fascine mats will be constructed of willows measuring from 2 to 6 inches in thickness at the butt end. The fascines will be 16 inches in diameter when tightly compressed. In continuous revetment work these mats will preferably be 1,000 feet or more in length.

The framed type of mattress such as used in the fourth district shall be constructed of willows 2 to 6 inches in thickness at the butt,

placed as close together as practicable, and bound together by suitable framing to form a mat of brush 16 inches in thickness. The separate units of the framed mats shall be laid in such manner as to form a continuous covering of the sloping bank and 50 feet beyond the foot thereof as defined in paragraph 1.

7. For sinking mattresses and holding them in place, about 1,600 pounds of stone or concrete blocks per square of 100 feet shall be used. The ballast should consist of stone or concrete blocks weighing about 40 pounds each, evenly distributed over the surface of the mats. The limiting weights of ballast units should be from 20 to 60 pounds.

8. Where departure from these instructions are considered necessary by the district engineers, special report and subproject shall be submitted to the commission and will be subject to its approval.

9. All resolutions and instructions of the commission or its agents relating to revetment work which are in conflict herewith are hereby rescinded.